A TREATISE

ON

MEDICAL ELECTRICITY,

THEORETICAL AND PRACTICAL.

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MEDICAL ELECTRICITY,

THEORETICAL AND PRACTICAL;

AND ITS USE IN THE TREATMENT OF PARALYSIS,
NEURALGIA, AND OTHER DISEASES.

BY

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"That, which forms the invisible but living weapon of the electric eel; that, which liberated by the contact of moist dissimilar particles circulates through all the organs of animals and plants; that, which flashing from the thunder-clouds illumines the wide skyey canopy; that, which draws iron to iron, and directs the silent recurring march of the guiding needle;—all, like the several hues of the divided ray of light, flow from one source, and all blend again together in one perpetual force, which is diffused every where."—Alexander von Humboldt, Aspects of Nature.

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PREFACE.

There are few remedies employed in the treatment of disease, on the value of which the professional mind is less settled than on that of galvanism. Enthusiastic panegyrists contended fifty years ago, and contend still, that it is a therapeutical agent superior to all hitherto discovered, whilst the great majority of the profession entertain serious doubts as to the reality of the remarkable successes which are now and then recorded by medical galvanists.

The differences of opinion about the therapeutical value of electricity are readily to be understood if we bear in mind that the mode in which electricity is applied has an all-important bearing upon the results. It is true that even by a careless employment of galvanism a few accidental successes have been obtained; but in ninety-nine cases out of a hundred, empirical galvanists, being unacquainted with the physiological effects of electricity, have been disappointed, and have brought the remedy into undeserved contempt.

We know that, whatever may be the properties of the nerves, they can be called into action by galvanism. But the effects

are widely different according to the form of electricity that is used; again, the quantity and intensity of electricity are both of great importance; not less so the mode in which it is transmitted to the human body, and the length of time during which its action is kept up. In fact, we are able, by merely varying the modes of applying electricity, to arouse or to kill the vital power of the nerves, and to diminish or to increase their properties. Hence electricity can only be expected to be of service in the treatment of disease, if we are guided in its use by an exact knowledge of the physiological effects which it will invariably produce. I have, therefore, been most anxious to render the physiological part of my work as complete and comprehensive as possible.

That there is at present so little certainty respecting the physiological and therapeutical effects of electricity, is in some measure due to the vast extent of the field that is to be explored, and to the comparatively short time that has elapsed since scientific researches of this kind have been undertaken; also to the intentional falsehoods that have been published, even in the present time, about pretended cures by means of electricity; and especially to the small number of observers who have devoted themselves to the study of these phenomena. We possess a large amount of valuable information and experience concerning the effects of internal remedies upon the system; we know where to procure and how to prepare most drugs; we know how to combine them, and in what cases and in what doses to administer them with advantage. But in respect to electricity we have no such certainty. What form of electricity should be

used? in what cases should it be employed? shall we act indiscriminately upon the different tissues, skin, muscles, and nerves, or shall we limit the action of electricity to each one singly? It is easy to understand that we cannot expect beneficial results from the application of electricity, if it is applied by empirical galvanists; if the cases are not well selected; if the apparatus employed does not possess those qualities which are necessary for medical use; if the dose of electricity given is too large or too small, and if, instead of acting upon the diseased part alone, the whole body, or part of the body, is acted upon. If, on the contrary, such mistakes as the above are avoided, electricity will be found a most valuable therapeutical agent, by means of which many morbid states of the system may be relieved, and even wholly cured.

It no doubt sometimes happens that in cases which to all appearance are suited for electric treatment, and in which the agent has even been judiciously employed, it nevertheless produces little or no benefit. In fact, electricity is as little infallible as any other remedy we possess. But nobody will doubt the remedial powers of quinine, if it should happen to leave uncured a few cases of ague; and croton-oil will always be reckoned amongst our most efficacious aperients, although it does not invariably relieve constipation.

There is another important point upon which I feel obliged to dwell; patients are recommended by their Physicians to undergo a course of galvanic treatment in many instances only after every other remedy has been tried without success, and

when the disease is of such long standing as to afford but little hope of ultimate recovery. What beneficial results might be obtained in certain affections of the nervous system, if the electric treatment were resorted to in an earlier stage of the complaint, may be conceived from a perusal of the chapter in which the effects of Faradization in a number of cases of hysterical aphonia are detailed. I shall be especially gratified if I succeed in inducing more frequent recourse to the electric treatment in certain forms of neuralgia, which defy all other therapeutical treatment, and which are wonderfully amenable to electricity.

Finally, I must allude to the mistake frequently made of employing galvanism alone without any internal remedies. I am quite satisfied that some affections of the nervous system can be cured by electricity alone; but in the majority of cases a simultaneous internal treatment is of the greatest importance, and should not be neglected if we wish to increase the chances of success.

Most of the cases which are reported in this volume have been observed and treated by me either in one of the Metropolitan Hospitals—King's College, St. Mary's, and Samaritan Free Hospital—or in the private practice of eminent members of the profession, to whose kindness in sending me cases for the electric treatment I beg to tender my sincerest thanks.

2, *Manchester-street, Manchester-Square,*
March, 1859.

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CHAPTER I.

FORMS OF ELECTRICITY.

In the present state of physical science it is generally admitted that all bodies contain a very subtle fluid called *natural electricity*, and composed of two contrary fluids, which are termed positive and negative electricity. We suppose these fluids to consist of an infinite number of smallest particles or molecules, each of which possesses attractive and repulsive powers, the molecules of one attracting those of the other, whilst the molecules of the same fluid repel each other. Whilst bodies are at rest, these fluids exist in such proportion that, although they do not destroy each other, their effect is counterbalanced; since at the same distance the attractive power of one of the fluids is equal to the repulsive power of the other. Natural electricity must therefore be decomposed, if an action shall be perceptible. Decomposition of the natu-

ral electricity is brought about as soon as disturbances of any kind are impressed upon bodies, whereby a derangement is produced in the equilibrium of the molecules; as for instance, when bodies are subjected to friction, heat, chemical action, etc. By such and other means an electro-motive force is called into existence, which separates from each other the two fluids formerly united; natural electricity is decomposed and *active electricity* liberated, the nature and intensity of which present certain differences, which depend upon the nature of the body from which it is derived and upon the action by which it is developed; but active electricity, whatever may be its source, is identical in its nature; it exerts attractive and repulsive powers, produces heat, light, shocks, magnetism, and is ready to tear asunder the elements of chemical compounds.

The principal sources of electricity are friction, chemical action, magnetism, and the animal body; they will be briefly considered in the following pages. We shall first take a short glance at static electricity, or electricity produced by friction; then proceed to examine dynamic electricity, under which head are comprehended both galvanism and electro-magnetism; and finally, sketch the present state of our knowledge in animal electricity, such as is produced by the general metamorphosis of matter in the living body.

I. *Static Electricity.*

Above two thousand years ago the Ionian philosopher,

Thales, discovered that pieces of amber, when rubbed with dry cloth, attract light bodies which are placed in their neighbourhood; hence he concluded that amber possessed a soul, and was nourished by the attracted bodies. We now know that amber, when rubbed, acquires the property of attracting light bodies, such as bits of paper, merely because by friction the natural electricity of amber is decomposed, and negative or resinous electricity is accumulated in the state of rest upon the rubbed body. If it now be approached to bits of paper, the negative electricity with which the amber is charged, necessarily exercises its attractive and repulsive powers; it decomposes, forthwith, the natural electricity of the bits of paper, repelling into the ground the negative electricity of these bodies, which now being charged with positive electricity immediately obey the attraction exercised upon them by the negatively electrized amber. For amber, glass or wax may be substituted.

Of all the different forms of electricity, static electricity exercises the most considerable attractive and repulsive powers, even at a distance; the energy, however, with which these attractions and repulsions occur, is always greater in proportion as the two bodies between which they are exercised are nearer to each other. When the natural electricity of bodies has been decomposed by friction, the fluids remain either in a state of rest accumulated upon insulating bodies, or they travel towards each other to neutralize each other. Neutralization takes place between them, when the bodies charged with con-

trary fluids are brought near to each other; in the neutralization of the two contrary electricities a spark is produced, which is capable of heating a wire and of magnetizing bars and needles. If the hand be brought near to the conductor of a common electrical machine in action, sparks are immediately seen to pass between the hand and the conductor; they produce a sharp pungent sensation in the skin; they may also affect the tongue and the eyes in a special way. The *quantity* of frictional electricity is always very small, but it possesses a high *tension;* it is easy, therefore, to draw very large sparks from the common electrical machine, whilst by large voltaic piles, which furnish an enormous amount of electricity, but which is of low tension, only small sparks are produced.

Neutralization may also be brought about between the contrary electricities, if the bodies charged with them are at a considerable distance from each other; for this it is only necessary that a communication should be established between the bodies by means of an insulated conductor.

In the moment of neutralization, electricity is no more in the state of rest, but in the state of motion or the dynamic state. This state of motion is instantaneous, if the two bodies, which were charged with contrary electricities, acquire no more electricity after that which they had before has once become neutralized; this instantaneous dynamic state is termed the *electric discharge.* The action of electric discharges may be very violent, especially if we employ the Leyden jar, by means of which rather

large quantities of electricity may be accumulated under a small surface. If a jar be discharged through the human body, a violent shock is felt, which may be transmitted through a file of men forming a chain; if we employ a battery composed of a number of jars, we may easily kill large animals by the discharge. The mechanical force of a moderate discharge can be used, as we shall see hereafter, for disintegrating calculi in the human bladder.

A discharge is instantaneous; but if the two electricities be constantly renewed, one of the bodies deriving from any source a continuous supply of positive, and the other one a like supply of negative, electricity, there will be, of course, a continuous neutralization produced either through the air with sparks, or through a conductor. This continuous dynamic state is termed the *electric current*. The essential difference between a discharge and a current is, that a simple discharge, although it produces a number of other effects, has no action upon a magnetized needle; whilst an electric current is capable of deviating it from its previous position. It is easy to understand that a rapid succession of discharges will form so many instantaneous currents, by which the magnetized needle of a galvanometer may be deflected just as it is by voltaic or electro-magnetic currents.

The chemical action of frictional electricity is very feeble, as the quantity of matter decomposed is not proportionate to the intensity, but to the quantity of electricity employed, and the quantity of frictional electricity

is very small. The voltaic pile yields an enormous quantity of electricity, and is, therefore, most powerful in producing chemical decompositions. Faraday has calculated that a Leyden battery would require to be charged by 800,000 turns of a powerful plate machine of fifty inches in diameter, to supply electricity sufficient to decompose a single grain of water, which by Grove's battery can be done in five seconds.

II. *Dynamic Electricity.*

A. *Galvanism.*

If two heterogeneous metals be connected by a conductor moistened with water, we notice various phenomena, the cause of which is ascribed to an agent developed by the connection of the metals, and called galvanic electricity, after Luigi Galvani, of Bologna, who discovered this form of electricity, in 1786.

Up to a very recent time galvanism was also termed electricity by contact, since natural philosophers had generally adopted Volta's theory, that the liberation of galvanic electricity is entirely due to the contact of the two different metals, whilst the liquid between them merely plays the part of a conductor. It is especially by the experimental researches of Davy, Becquerel, M. de la Rive, and Faraday, that Volta's theory has been refuted, and the fact established, that the real source of galvanic electricity is not contact, but the chemical action of two heterogeneous conducting bodies; that contact is only a condition most frequently necessary, but not always

indispensable to the manifestation of the electric signs; that galvanic electricity may be produced by any chemical action, not only by the action of a liquid upon a solid, which it is true produces the most remarkable electric phenomena; but, likewise, by the action of two liquids upon each other, or even by gases acting upon solids and liquids. The electricity yielded by the voltaic pile is, therefore, not dependent, either in its origin or in its continuance, upon the contact of the metals with each other, but is entirely due to chemical action, and is proportionate in its intensity to the intensity of the affinities concerned in its production; and in its quantity to the quantity of matter which has been chemically active during its evolution. In fact, every chemical action is accompanied by a disturbance in the equilibrium of the molecules of a body, and consequently by a liberation of electricity. Where there is no chemical action, no electricity will be liberated; we may thus, for instance, establish the most perfect contact between a pair of iron and copper, and immerse it into a well-conducting liquid, such as a solution of potash; but nevertheless the pair remains inactive, because the liquid is incapable of exercising a chemical action upon either of the metals of the pair.

The original voltaic pile is constructed in the following way:—A copper disc is placed upon a glass plate, a zinc disc upon the copper disc, and a circular piece of cloth, well moistened with water, or salt water, or acidulated water, upon the zinc disc. A second similar pair is piled

on the first, a third on the second, and so on. The copper of the first and the zinc of the last pair are termed poles of the pile; they are the doors or ways by which the electric current passes into and out of the decomposing body. As soon as the poles of the pile are united, the water moistening the cloth between the pairs becomes decomposed, and hydrogen is attracted to the copper, oxygen to the zinc pole. By this chemical action an electro-motive force is engendered, which decomposes the natural electricity of the metals into positive and negative electricity; the former being accumulated upon the surface of the zinc, the latter upon the surface of the copper. If the two poles of the pile are connected by a conducting wire, the two contrary electricities travel towards each other to neutralize each other; and as there is a continuous supply of contrary fluids, there will be a continuous neutralization, or a continuous electric current, as long as the surface of the metals remains unaltered. It is, however, inherent in the construction and action of the ordinary voltaic pile, that the heterogeneity of the two metals is soon destroyed. The copper of each pair is covered with hydrogen arising from the decomposition of water, and with oxide of zinc arising from the decomposition of the sulphate of zinc, which latter salt is constantly formed by the action of the diluted sulphuric acid upon the zinc. The surface of the copper is, therefore, rapidly altered, and soon rendered almost similar to that of the zinc, which is, on its own part, being oxidized. Hence it results, that the power of the voltaic

pile is very variable, and after a certain time will totally disappear.

In order to avoid this inconvenience, Becquerel proposed to plunge each of the metals into a special liquid, both being separated from each other by a porous diaphragm which would allow communication between the two liquids. He constructed a battery contained in a cylindrical vessel of glass or porcelain; a cylinder of zinc is placed into this vessel, and acidulated water poured in the space between the vessel and the zinc. In the interior of the cylinder of zinc is placed a bladder, containing a copper cylinder and a concentrated solution of sulphate of copper. When the poles of the pile are connected, both the water and the solution of sulphate of copper are decomposed. One part of the oxygen liberated combines with zinc to form oxide of zinc, which combines again with sulphuric acid to form sulphate of zinc; another part of the oxygen combines with hydrogen to form water; besides, a thin film of copper is deposited on the surface of the copper cylinder, which is, therefore, not altered. It is easy to understand that Becquerel's battery will furnish a much more constant current than the original voltaic pile.

Very much like Becquerel's battery, is Daniell's pile, which consists of zinc plunged into salt water, or acidulated water, and of copper immersed into a solution of sulphate of copper. The chemical decomposition brought about in this pile is exactly the same as in Becquerel's battery; but there are two important ameliorations in-

troduced into Daniell's pile. On the one hand, it has a diaphragm of porous earth, which is not so easily spoilt as a diaphragm made of organic substances, such as bladder, sailcloth, pasteboard, etc., and which can be conveniently employed in the form of a vessel; on the other hand, the zinc of the pair is amalgamated, which prevents its being attacked, when the poles of the pile are not united by a conductor, without diminishing the effect of the zinc in the production of electricity.*

In Grove's battery, which is one of the most powerful that have been constructed, the copper is replaced by platinum, and the solution of sulphate of copper by nitric acid, into which the platinum is immersed. Amalgamated zinc is plunged into diluted sulphuric acid, and both liquids are separated by a porous diaphragm of unglazed porcelain. Nitric acid has the double advantage of containing much oxygen, whereby the intensity of the current is increased, and of being a better conductor than sulphate of copper, so that the current is more easily transmitted. The hydrogen resulting from the decomposition of water is not developed upon the platinum, but changes nitric acid into nitrous acid; the liquid, therefore, assumes a brown color, and afterwards passes into green; but the surface of the platinum remains always clean. On the other hand, zinc is oxidized by the nascent oxy-

* Zinc is amalgamated (covered with a coat of mercury) by pouring mercury and diluted sulphuric acid upon the zinc. The surface of the zinc is oxidized and cleansed by the action of the acid, so that mercury will easily adhere to it.

gen, and sulphate of zinc remains in solution. The action of the pile is arrested after a certain time by further chemical changes which are going on in the nitric acid, and result from the development of hydrogen, whereby at last the acid enters into ebullition.

Bunsen's pile differs from Grove's only in this particular, that carbon, which is more negative and much cheaper than platinum, is substituted for the latter metal. In the original battery a cylinder of carbon, which is open at the bottom, is placed in a cylinder of glass, and a porous diaphragm of unglazed porcelain, containing the zinc, is placed in the cylinder of carbon; nitric acid is then poured between the glass and the carbon, and diluted sulphuric acid into the porous diaphragm containing the zinc. This form, however, has lately been simplified, so that the porous diaphragm of unglazed porcelain is no longer used, carbon itself being porous; and in its stead a cylinder of carbon is employed, which is closed at the bottom, filled with powdered carbon and moistened with nitric acid.

In Smee's pile, plates of platinized silver are substituted for carbon. Many other piles have been constructed, which space does not allow us to describe. The most constant current is furnished by the piles of Daniell, Grove, and Bunsen.

Mistakes are very frequently made regarding the *direction of the current* of the galvanic batteries, a circumstance which, in my opinion, arises chiefly from the fact, that the direction of the current is different in the ordi-

nary voltaic pile and in the constant batteries; the zinc forming the positive pole in the former, and the negative pole in the latter. In order to understand this, we must analyze the process which is going on, as soon as the two metals of a single pair, or the poles of a pile, have been connected by conducting wires, or electrodes.* The two contrary electricities which are being liberated by the electro-motive force, travel towards each other to neutralize each other, that is to say, a positive current is travelling towards the negative electrode, and a negative current towards the positive electrode. It is, however, generally understood that, if we are to tell the direction of the current, in order to avoid mistakes, only the positive current travelling towards the negative electrode is taken into account. The positive pole is that to which oxygen is attracted if water be decomposed by the action of the pile; the negative pole that to which hydrogen is attracted. In a single galvanic pair, the positive electricity is accumulated on the surface of the zinc, and negative electricity on the surface of the copper. In the ordinary voltaic pile, the positive pole is at the top, where the pile is terminated by a disc of zinc; as by the electro-motive force positive electricity is driven from the copper to the zinc, whereby the zinc is made positive and the copper negative; and the negative pole is therefore at the bottom of the pile, where it is terminated by a disc of copper. If, however, the metals are plunged into separate vessels, as is the case in the constant batteries, the direc-

* Electron, hodos = way of electricity.

tion of the current becomes different. In these batteries the positive current travels from the zinc through the liquid to the copper, from the copper to the zinc of the next pair, and through the liquid again to the copper; so that the copper, which forms the negative pole in the ordinary voltaic pile, will form the positive pole in the constant batteries; and the zinc, which forms the positive pole in the voltaic pile, will form the negative pole in the constant batteries. Therefore, in Daniell's pile the positive pole will be formed by the copper, in Grove's pile by the platinum, in Bunsen's pile by the carbon, in Smee's pile by the silver; while zinc forms the negative pole in all these batteries.

Various phenomena are observed when the neutralization of the two contrary electricities is brought about. When the electrodes are brought together, a spark passes between them. Voltaic sparks are very small, since galvanism is of low intensity,* although its quantity is large. The tension of the electricity produced by the revolution of a large glass plate is so high, that sparks from ten to fourteen inches in length may be drawn from the conductor of the machine in action, whilst the sparks obtained by a hundred plates of Grove's battery are only one thousandth of an inch in length.

If a wire of iron or any other metal, an inch or two in length, be employed to connect the two poles of a

* That voltaic electricity has a certain tenison, becomes evident, if we examine the extremities of a pile by means of the ordinary electrometer; it is then perceived that the gold leaves repel each other at the same extremity, whilst they attract each other at different extremities.

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voltaic pile, the neutralization of the two electricities is brought about by this wire; which rises in temperature, becomes incandescent, sheds a sparkling light, and may even be melted if the action of the pile be sufficiently powerful. The light is only produced when the elevation of temperature becomes sufficiently great to render the conductor incandescent. The amount of heat produced by the transmission of electricity is more considerable in wires of the same metal, in proportion as they present less volume to the action of the liberated heat, and offer a greater resistance to the passage of electricity. Wires, which are rendered incandescent by the action of voltaic electricity, can be conveniently employed to produce the effects of an actual cautery; it is certain that the galvanic cautery acts rapidly and energetically, and that its action may be exactly limited to the part which we intend to cauterize.

Of all kinds of electricity, that produced by the voltaic pile is the most powerful to bring about chemical decompositions, in consequence of the large quantity of electricity yielded by the pile. If water be interposed between the poles of the pile, it is rapidly decomposed into its elements, as well as the liquid placed between the pairs of the pile itself. The hydrogen always accumulates around the negative pole, the oxygen around the positive pole. Acids are attracted to the positive pole, as is oxygen, and alkalies to the negative pole, as is hydrogen.* The chemical action of the voltaic pile can be

* Bodies which are directly decomposed by an electric current are termed electrolytes.

used in surgery for the cure of aneurisms, as coagulation of the blood is easily produced by galvanic electricity around the positive pole of the pile, to which the acids of the salts of the blood are attracted; on the other hand, it can be used for the dissolution of calculi in the human bladder, as proved by the experiments of Prévost and Dumas on animals, and by the successful operations of Dr. Melicher on living men.

The physiological phenomena produced by galvanic electricity are very remarkable. If conductors connected with the poles of the pile be touched with both hands, a series of shocks is felt, which may be very painful. When they are applied to any point of the face, a sparkling light is seen by the one subjected to the experiment; if the tongue be touched by the conductors, a peculiar sensation of taste is produced; if they be applied to the ears, sounds are heard. These phenomena will be described at greater length in another part of this volume.

We have seen that, if the poles of the pile be connected by a conducting wire, the two contrary electricities, which are liberated by the electro-motive force, travel towards each other to neutralize each other. The amount of electricity produced depends upon the intensity of the electro-motive force or the amount of the surface of the battery; but there is a difference between the quantity of electricity *produced* and the quantity of electricity that is *travelling* in a certain space of time through a conjunctive wire, by which the poles of the pile are connected. The amount of electricity travelling depends not

only upon the intensity of the electro-motive force, but also upon the resistance offered to the passage of electricity through conducting bodies, and upon the tension with which electricity is driven through a conjunctive wire.

All bodies, through which an electric current is propagated, offer a certain resistance to the passage of the current, and consequently diminish its intensity. There are no absolutely perfect conductors of electricity. If the magnetized needle of a galvanometer be brought into the circuit of a pile, the needle will be deflected to a certain extent by the electric current; if we then interpose copper or silver wires, which are the best conductors of electricity, between the poles, the deflection of the needle will be less considerable than before; this shows that the power of the current has been diminished by the interposition of the wires into the circuit. The resistance of bodies varies according to their chemical nature and form.

Metals offer the least resistance to the passage of a current; they are, therefore, termed good conductors, as they permit of tolerably rapid propagation of electricity. The conductibility of the several metals is different. Silver is the best, and mercury the worst conductor; after silver ranks copper, which conducts better than gold; gold conducts better than iron; iron better than platinum; platinum better than lead. The resistance offered to an electric current is especially great, if it passes from a liquid to a solid, or from a solid to a liquid. Liquids conduct much worse than metals, but elevation of tempera-

ture increases their conducting power; whilst heat diminishes the conductibility of metals. To give some instances, the resistance offered by a concentrated solution of sulphate of copper to the passage of an electric current, is sixteen million times greater than that offered to it by metallic copper; the resistance of distilled water is four hundred times greater than that offered by sulphate of copper. Therefore, an electric current will pass more easily through a copper wire of ten thousand miles in length than through a layer of water of one inch in length.

The conductibility of bodies does not only depend upon their chemical nature, but also upon their form. If an electric current of the same intensity is made to pass through wires of the same metal and diameter, but of different length, we find that the current loses power in proportion to the length of wires through which it is caused to pass. If, on the other hand, the current passes through wires of the same metal and length, but of different diameter, the power of the current is increased in proportion to the diameter of the wires. Thus, for instance, a copper wire a hundred feet long and the twelfth of an inch in diameter, will offer the same resistance as a copper wire two hundred feet long and a sixth of an inch in diameter. To give another example, the resistance offered by the arm of man is the same as that offered by the leg; since both the length and the diameter of the leg are nearly double those of the arm.

The human body is a conductor only on account of the warm salt water it contains, and therefore, when the epi-

dermis has been removed, or conveniently moistened, it conducts ten to twenty times better than cold distilled water. The least resistance will therefore be offered by the animal fluids themselves; the mucous membranes will conduct better than the nerves, the nerves better than the brain and the spinal cord, and the bones better than the hair and nails. The epidermis in its dry state will offer a very great resistance to the passage of an electric current; but if it be moistened, its resistance will be much diminished, and a current may now penetrate through the skin, without injuring it, to a nerve or a muscle.

Thus, for instance, if we want to experience the effect of the galvanic current upon ourselves, and the pile is not very powerful, it will not do to touch the poles of the pile with dry fingers; but as soon as the fingers have been moistened we immediately feel a shock which goes up to the wrist, to the elbow, or even to the shoulder, according to the intensity of the current. If we immerse the hands into separate vessels filled with warm salt water, one of them communicating with the positive, the other one with the negative pole of the pile, the shock will be felt much more strongly, because the resistance of the skin is further diminished. If the epidermis be quite removed, the effect will be stronger still; thus a small scratch on a part of the hand to which one of the electrodes is applied, will facilitate very much the transmission of the shock, and the production of the peculiar sensation caused by the passage of the current through the limbs.

Professor Edward Weber, of Leipzig, made the first ex-

periments on the conductibility of the human body.* He found that it conducts about ten to twenty times better than cold distilled water, and fifty million times worse than copper. A few years later, Lenz and Ptschelnikoff, at St. Petersburg, made another series of interesting experiments on the same subject.† They used Clarke's magneto - electric rotation machine, and employed as measurer of the current a multiplier which was placed at a distance of eighteen feet from Clarke's apparatus, in order to avoid any action of the horse-shoe magnet upon the magnetized needle of the multiplier; the deflections of the needle were observed by means of a telescope. Two vessels were then filled with a well-conducting liquid, viz. sulphuric acid diluted with hundred parts of water; one of the vessels was connected with one of the poles of Clarke's machine, by means of a short and thick copper wire, which did not present any resistance to passage worth mentioning; one of the ends of the multiplier was immersed into the other vessel, whilst the other extremity of the multiplier was connected with the other pole of the magneto-electric machine. Now, a man, whose resistance to the passage of the electric current was to be measured, was ordered to immerse his hands in the two vessels to close the circuit; the magneto-electric current then passed through the human body to the magnetized needle of the multiplier. At first they noticed the deflection obtained,

* Quæstiones physiologicæ de phænomenis galvano-magneticis in corpore humano observatis. Leipzig, 1836.

† Uber den Leitungswiderstand des menschlichen Körpers gegen galvanische Ströme; in Poggendorff's Annalen. Vol. lvi., 1842, p. 429.

when the extremities of the multiplier were connected with the spiral of Clarke's apparatus without the intervention of any foreign body; they afterwards noticed the deflection obtained, when the human body was interposed into the circuit; at last the deflection obtained, when the human body was again removed from the circuit. From the first and third deflections the medium was taken, and the result compared to the amount of the second deflection.

Lenz and Ptschelnikoff made their experiments upon a working man, two persons of rank, a boy of seven years, a girl of nineteen, and a young man of seventeen. It seems to have been immaterial if the immersed part was near the conducting wire, or far from it; as the differences produced in the deflections of the needle by changing the position of the wire did not amount to one-tenth of a degree. It appeared, however, that the amount of surface of the immersed part of the body is of the greatest influence. Thus the resistance was 34°,09 if only the forefinger was immersed into the liquid; the resistance was diminished to 19°,20 if the middle finger was also immersed; it was only 6°,06 if the whole hand was plunged into the liquid.

One of the principal results of these experiments was, that the conductibility of the human body is altogether different, according to the conducting liquid that is used. Thus, if water from the Neva was put into the two vessels, the resistance amounted to 16°,53. If one part of sulphuric acid was added to a hundred parts of water, the resistance was immediately diminished to 6°,06. A little

scratch made on the hand further reduced the resistance to 4°,81; and if four parts of sulphuric acid were added to a hundred parts of water, the resistance was only 4°,37; that is to say, four times less than if water only was used as a conducting liquid. It is, therefore, obvious that the greatest part of the resistance of the human body is due to the epidermis, the removal of which notably diminishes the resistance. The resistance of the epidermis may also be more or less counterbalanced by the use of a well-conducting liquid.

Besides, it appeared that the resistance offered by young people is greater than that of elderly persons; that the resistance offered by the hand of working men is greater than that of the hands of persons who have not been exposed to hard work; that the resistance offered by the right hand is greater than that of the left. Lenz and Ptschelnikoff have calculated the resistance of the whole body being equal to a copper wire of one millimeter in diameter, and 300,010 feet long, if water diluted with one per cent. of sulphuric acid was used as conducting liquid; but if four parts of sulphuric acid were added to a hundred parts of water, the resistance appeared to be equal to a copper wire of 213,000 feet long.

There are certain differences in the conductibility of different persons, and of the same individuals at different times, which have not yet been satisfactorily explained. It is well known that some persons are naturally better conductors of electricity than others; and this is certainly in some measure due to the great variety which exists in

the quantity of perspiration in different individuals. Thus, for instance, when shocks from a Leyden jar are transmitted through a number of persons forming a chain, there are people in the chain who will feel the shock very slightly, or not at all, and who will even stop the propagation of electricity; while other individuals will feel the shock very violently. Now, this might be readily understood, if the hands of such persons who stop the shock should happen to be quite dry, or the epidermis to be very thick; but, in many instances, such is not the case; sometimes persons will stop the propagation of electricity, although in them the epidermis of the hands is very delicate, and even if it be purposely moistened, in order to facilitate the transmission of the shock; at other times, the same persons will feel the shock very distinctly. Similar observations have been made in regard to lightning. Thus, a single person may be struck in the middle of a group of men, while all others may remain untouched; and, on the other hand, a number of persons standing together may be killed by the stroke, while one of them will escape without injury. It is also understood that certain Indians and negroes can handle the electric eel without experiencing shocks; and Mr. Flagg asserts,* that if a number of persons join hands and one touch the eel, they are all equally shocked, unless there should happen to be one of the number incapable of being affected by the eel, which is—he says—"the case of a very worthy lady of my ac-

* Transactions of the American Phil. Society, held at Philadelphia, 1786. Vol. II., No. 13.

quaintance, who can handle this fish at will." (It is said that this lady suffered from hectic fever.)

Researches on the relative conductibility of the different animal tissues are of recent date. The old physiologists, who had not experimented on the subject, believed that the nerves were the best conducting tissue of the animal body. But it resulted from the very first experiments which were made on this matter by Person, in 1830, that the nerves are no better conductors than the muscles and other humid animal substances.*

In 1843 a series of experiments was undertaken by Matteucci, who was led to the conclusion that the muscles are the best conducting tissue of the animal body, that the brain, the spinal cord, and the nerves are not very different from each other in this respect, and that they conduct four times worse than the muscles.†

Matteucci's views were almost generally received by the Profession, but we shall see presently, that the method he employed in his researches is open to objections, and does not yield correct results. In order to ascertain the relative conductibility of nerves and muscles, he took a layer of the cerebral substance, a piece of the sciatic nerve, and a piece of a muscle from the thigh of a rabbit recently killed; he then reduced these substances to slices of the same thickness, and caused the continuous current of twelve batteries to pass through this chain of animal sub-

* Sur l'hypothèse des courans électriques dans les nerfs; in Magendie, Journal de physiologie expérimentale. Paris, 1830.

† Traité des phénomènes électro-physiologiques des animaux, etc. Paris, 1844, p. 47; and Comptes rendus 1843, 23.

stances lying on an insulating plane. He now employed two different ways for comparing the resistance separately offered by nerves and muscles. At first he touched pieces of nerves and muscles of equal length with the extremities of a sensitive galvanometer multiplier, which were held at equal distances from each other; and obtained more considerable deflections of the magnetized needle when he touched the muscle than when he touched the nerve; the amount of deflection being inversely proportional to the resistance offered by the different substances to the passage of the current. He afterwards changed the distance of the extremities of the galvanometer multiplier, so as to obtain equal deflections of the magnetized needle, by touching either the nerves or the muscles; the resistance to passage being in this instance inversely proportional to the length of animal substances comprised between the extremities of the multiplier; and he found that, in order to obtain the same deflection of the needle, he had to approach the extremities of the multiplier when he touched the nerves; whilst when he touched the muscles, he was obliged to increase the distance between the extremities of the multiplier. From this Matteucci calculated that the muscles conduct four times better than the nerves, whilst the nerves conduct a little better than the brain and the spinal cord. The experiments of Matteucci were repeated, and, on the whole, confirmed, by Dr. Schlesinger, of Vienna.*

* Die Elektricität als Heilmittel. Zeitschrift Wiener Aerzte, 1842, July.

Several objections, however, must be made to Matteucci's method. At first, it has been pointed out by Dr. Du Bois Reymond, that the slices of the different tissues can never be exactly of the same length and diameter. Besides, Matteucci neglected to measure the intensity of the current of the battery; and finally, it seems strange, that he should have obtained exactly the same results by both of his methods; as in the former of them an influence must have been necessarily exercised by polarization,* whilst there was no such influence in the latter proceeding.

We, therefore, cannot accept Matteucci's researches as conclusive, and need not be surprised that other results have been obtained by means of a new and very ingenious method recently devised by Professor Eckhard, of Giessen.† The result at which Professor Eckhard has arrived is, that the resistance offered to the passage of an electric current by the muscles, tendons, nerves, cartilages, and bones, is not always the same, because the amount of water in the same tissues is variable. Indeed, there are not only dif-

* We know that the most feeble electric current cannot traverse an electrolyte liquid without decomposing it; therefore the electrodes immersed into such a liquid will soon be covered upon their surface with deposits, either gaseous or solid. Now the liquid will immediately exercise a chemical action upon the deposits with which the surfaces of the electrodes are covered; and thus, secondary currents will be produced. This is called polarization, or secondary polarities. Polarization is acquired by the electrodes whenever they have transmitted electric currents; and electrodes are called polarized, if they develop a secondary current, in consequence of having been traversed by a primary current.

† Beiträge zur Anatomie und Physiologie. Giessen, 1858. Vol. I. p. 57.

ferences in this respect between different individuals of the same species, but the same tissues taken from different parts of the same body will present differences in the amount of water they contain. Thus it is a fact well known to anatomists, that the median nerve at the forearm contains less blood-vessels than the sciatic nerve immediately after it has emerged from the pelvis. Therefore, the median nerve does not conduct so well as the sciatic nerve. Finally, it must be considered that a more or less active evaporation of water is always going on during the time that the tissues are reduced to such a shape as to be fit for observation; whereby certain variations must invariably occur, according to the temperature, and the greater or less humidity of the air.

As the different animal tissues cannot be well reduced to such a shape that the longitudinal and transverse sections are perfectly alike,* this being a necessary condition for the exact calculation of their resistance to passage, Professor Eckhard did not compare directly the resistance offered separately by the tissues themselves, but first determined the resistance offered by any piece of animal tissue; from this he afterwards took a cast in plaster of Paris, by means of which he formed a piece of glue perfectly like the piece of animal tissue already examined; and then measured the resistance offered by the piece of glue. The glue used for these experiments was always of the same concentration, and the experiments were not

* The only exception from this rule is formed by the lumbrical muscles and the nerves.

commenced before the different pieces of glue had been cooled down to the same temperature; the cooling was effected in a room filled with vapours of water. For determining the conductibility of muscular substance, Professor Eckhard took fibres from the body of a man, after the rigor mortis had disappeared; because, before this period has elapsed, it is not possible to form a piece of glue perfectly like the piece of muscle. In order to avoid the shrinking of the muscle that might be occasioned by the hygroscopic property of plaster of Paris, he covered the muscular fibres with a layer of fat, before he took the cast. After having determined the comparative resistance offered by the different animal substances and glue, it was easy to calculate the relative difference in the conductibility of the animal tissues themselves.

As measurer of the current a galvanometer multiplier of 8000 convolutions was employed, and, in order to avoid the influence of polarization as much as possible, copper wires, cemented in glass tubes, were taken as electrodes, the free extremities of which were immersed in a strong solution of sulphate of copper. The current itself was furnished by a single Daniell's battery, the constancy of which had been tested before; cushions of blotting paper, well moistened with the white of an egg, were immersed with one extremity in the liquid, their other extremity serving as electrode.

Professor Eckhard first determined the deflection suffered by the magnetized needle, if the circuit was closed by the cushions themselves. He then interposed a piece

of muscular substance, whereby the deflection was diminished to a certain extent; if a piece of tendon was interposed, the deflection was further diminished. He afterwards determined the deflections of the needle produced by the interposition of different pieces of glue corresponding to the pieces of muscles, tendons, etc. In this way he found that the muscles are the best conducting tissue of the animal body; that there is no remarkable difference in the conductibility of nerves, cartilages, and tendons, and that the bones are very imperfect conductors of electricity.

Having put the resistance of fibres taken from the sartorius muscle of man = 1, Eckhard found the resistance of the tendon of the gastrocnemius = 1,7 to 1,9; of the tendon of the semitendinosus = 2,2 to 2,4; and of the tendon of the extensor carpi radialis = 2,3 to 2,6; therefore the middle amount of the resistance offered by tendons would be 2,1. The resistance offered by the cartilages of the ribs differed from 1,7 to 2,4; middle amount = 2. The resistance of nerves taken from the brachial plexus was 1,9 to 2,4; that of the sciatic nerve 2,2; middle amount 2,1. The compact substance of the bones appears to conduct 16 to 22 times worse than the muscular substance. It is, however, difficult to make conclusive experiments as to the conductibility of the bones, because the bones must be sawn through if we want to get pieces fit for observation. If this be done without using a fluid, the small quantity of fluid contained in the bone will evaporate from the surface, in consequence of the heat

produced by friction; and if the bone be sawn through, the surface being always moistened with the white of an egg, it is to be feared that the amount of fluid would be artificially increased.

The results of Professor Eckhard's researches may therefore be summed up in the following:

The resistance of muscles is	= 1.
of cartilages	= 2.
of tendons	= 2,1.
of nerves	= 2,1.
of bones	= 19.

These numbers correspond with the amount of water contained in the animal tissues; for if we take the medium of all trustworthy chemical analyses of animal substances, which have yet been made, we find that

The muscles contain	76 per cent. of water.
The tendons	62.
The cartilages	62,5.
The nerves	52,5.
The bones	5.

The apparent incongruities in the numbers may be understood, if we consider that the conductibility of tissues is not exclusively due to the amount of water, but also to the quantity of salts contained in them.

Finally, a few words upon the meaning of the words *quantity* and *intensity* of the voltaic currents. We may collect a large amount of electricity from a single pair, if there be little resistance in the conjunctive wire; but as soon as the resistance of the conjunctive wire is in-

creased, much less electricity can be collected, unless care be taken to increase in proportion the resistance of the electro-motive apparatus itself, which is done by increasing the number of the pairs; that is to say, by forming a pile. If we compare a current, furnished by a single pair, passing through a short and thick conjunctive wire, with another current produced by a pile, the elements of which present the same amount of surface taken together as the single pair, and if the poles of the pile are connected by a long and fine wire, the *quantity* of electricity will be the same in both cases; but the electricity passing through a fine wire must necessarily be in a state of greater *density* than the electricity which passes through the thick wire. These differences in the density of voltaic currents are comprehended by the terms of quantity and intensity. The quantity of a current will be great if it be produced by a single pair of large surface, the poles of which are connected by a thick wire; the tension of a current will be high if it be produced by a pile consisting of a number of pairs, which are connected by a fine wire.

B. *Electro-Magnetism.*

Phenomena, showing the close relation that exists between electricity and magnetism, have already been observed centuries ago. By the fall of lightning now and then masses of steel or iron have been magnetized; watches have been stopped by the same cause—in consequence of the magnetization produced by lightning in the pieces of steel of the balance; the poles of mariner's compasses

have been altogether changed by the fall of lightning upon ships, an occurrence which has, in some instances, been attended with fatal results to sailors who have been guided in a contrary direction, and cast upon rocks, from which they thought they were receding at full sail.

In 1819, a Danish philosopher, Oersted, made the first scientific observation on the action of electricity upon a magnet. He found that when the two poles of a galvanic battery are united by a metal wire, which is placed closely above or below a magnetized needle, the needle immediately suffers a deviation, the extent of which is directly proportional to the power of the battery, and inversely proportional to the distance between needle and wire. The needle tends to place itself at a right angle to the conjunctive wire, and succeeds in attaining this position, when the current of the battery is very strong, and the needle very near to the wire.

Ampère then drew the attention of natural philosophers to the fact that the terrestrial magnetism prevents the magnetized needle obeying entirely the influence of the current, as that influence continually tends to reduce the needle to the plane of the magnetic meridian. To obviate this inconvenience he constructed the so-called *astatic needle*, composed of two magnetized needles placed in a parallel direction, whereby the influence of the globe is more or less paralyzed. But the two needles cannot, under any circumstances, be perfectly alike, nor placed in two directions exactly parallel, nor possessed of absolutely the same quantity of magnetism; and therefore the globe will

always exercise a certain amount of action upon the astatic system. But certainly the effect of an electric current upon a double needle is much stronger than upon a single; and a very feeble current, which is not able to deviate a single needle, will produce a marked effect upon the astatic system, especially if the wire by which the current is transmitted be bent, so that it is no longer above or below the needle, but forms two parallel branches, between which the needle is suspended; provided, of course, that the current cannot pass from one spiral to the other, which is prevented by covering the wire with an insulating envelope of silk or gutta percha. If there be two such spirals, the action of the current upon the needle is twice as powerful as if the wire had been only above or below the needle, and each further convolution of the wire will increase in proportion the action of the current upon the needle. This principle has been applied to the construction of the galvanometer multiplier, which was invented by a German philosopher, named Schweigger, and first employed in electro-physiological researches by M. Nobili. Du Bois Reymond has constructed multipliers of the utmost sensitiveness (with more than 24,000 convolutions,) by means of which he was enabled to detect the presence of electric currents in almost all the tissues of the living animal body.

Soon after Oersted's discovery had been made known, Arago found that the electric current strongly imparted the magnetic force to pieces of soft iron, steel, and other magnetic bodies, which did not possess it previously. He saw that when a fine iron wire was traversed by a strong

current, it acquired the property of attracting around itself iron filings, which immediately fell down again from the wire as soon as the current ceased to pass. Arago succeeded likewise in magnetizing needles by powerful discharges from a Leyden jar. If a copper wire covered with silk or gutta percha be rolled in the form of a helix around a bar of soft iron, and an electric current is caused to pass through the wire, the soft iron becomes a powerful magnet. Such temporary magnets are termed electro-magnets, in order to distinguish them from permanent magnets of steel. It is with great rapidity that soft iron is magnetized and demagnetized by an electric current. For showing the magnetic power produced in the soft iron by the passage of an electric current, it is well to give to the bar the form of a horse-shoe, as the poles of such a magnet are very near to each other.

Science had advanced thus far when Faraday discovered in 1831, that an electric current, as well as a magnet, is able by induction to develop electric currents in conducting wires. This is proved by the following experiments: Two conducting wires are placed on an insulating plane, parallel with and very near to each other; the two ends of the first wire are connected with the poles of a galvanic battery; the two ends of the second wire with the extremities of a galvanometer multiplier, to judge the electric movement in the wire by the deviation of the needle. At the moment when the current of the battery is caused to pass through the first wire, the needle of the multiplier communicating with the second wire is seen to

deviate, then to suffer some oscillations, and finally to come back to an equilibrium, which remains undisturbed as long as the current of the battery continues to pass through the wire. But as soon as the communication between the battery and the first wire is interrupted, the needle suffers another deflection in a contrary direction to that in which the former had occurred. Thus it is proved that the galvanic current which traverses the first wire determines in the second wire an instantaneous current at the moment when it begins to circulate, and another equally instantaneous current at the moment when it ceases to pass. The multiplier, however, indicates not only the existence of such instantaneous currents, but also their direction. If we compare the direction of the different currents, we find that the direction of the current induced in the second wire on *making* the circuit is *contrary* to that of the current of the battery, while the direction of the current induced in the second wire on *breaking* the circuit is *equal* to that of the current of the battery. We may notably increase the intensity of these instantaneous currents if we employ two copper wires of great length, covered with silk or gutta percha, and rolled around a wooden cylinder, or bobbin, so as to form two helices, the spirals of the wires being as near to each other as possible.

The intensity of induction currents is further increased by introducing into the cavity of the bobbin pieces of soft iron, which become magnetic under the influence of the current of the battery, and thereby produce other electric currents in the two wires; just as electric currents may be

induced in wires by a permanent magnet of steel. The currents produced by the magnetism of the soft iron are as equally instantaneous as the currents developed by the inducing current of the battery. They are not produced whilst the soft iron is a magnet, but only at the moment when the soft iron gains and loses its magnetism. Therefore the demagnetization of the soft iron has the same effect as breaking the current of the battery, in the production of an instantaneous induced current.

The power of the electro-magnet to increase the intensity of currents induced by a galvanic current, is different according to the shape and quantity of iron. It is enough for producing a remarkable effect, to have a single piece, or a hollow cylinder, of soft iron around which the copper wires are coiled, but the effect is increased if we take a bundle of iron wires; and yet more, if these wires are insulated from each other by a layer of varnish. It was formerly believed that the increased effect was due to the circumstance that the iron wires are softer than a solid cylinder, and therefore would become more strongly magnetized. But it has been proved by the researches of Professor Magnus, of Berlin, that such is not the case, the magnetism of a solid cylinder being equally strong as that of a bundle of wires of the same volume; that the effect is only increased in consequence of the bundle of wires conducting less well than the solid cylinder. If the poles of the battery are in connexion with the coil of wires, instantaneous currents are produced in the central soft iron, as well as in the wires that are coiled around

it. Now the current produced in the soft iron on breaking the circuit, retards notably the demagnetization of the soft iron; the magnetism of the soft iron will, therefore, disappear much more easily and rapidly if the production of currents in the soft iron is prevented as much as possible. The more rapid the demagnetization of the soft iron, the more notable will be its inducing effect. It is obvious that electric currents will be most easily produced in a solid bar of soft iron, less easily in a bundle of iron wires, and least easily if these wires are insulated by varnish.

We know from the researches of Professor Dove, of Berlin, that the intensity of an induced current is very much diminished, if we cover the electro-magnet by a closed envelope of a non-magnetic metal (brass or copper.) This is due to the development of induced currents in the metal envelope itself, whereby the effect of the magnetism in the soft iron is counterbalanced. The metal envelope does not prevent the action of the current upon the galvanometer, but it greatly diminishes the magnetizing as well as the physiological effect. From this we may draw two important conclusions: viz., that a metal envelope covering the electro-magnet can be employed as a regulator of the intensity of the current in physiology and therapeutics; and that the galvanometer does not indicate the intensity of the physiological effects of induction currents.

The first wire of the bobbin of induction, the ends of which are connected with the poles of the battery, is com-

paratively short and thick, as the inducing current of the battery which is propagated in it arises generally from a single pair, and the resistance of the conducting wire must be small, in order that a powerful electro-magnet may be produced by the current. But in the short and thick wire we have not only the inducing current of the battery, but another current which is much stronger and developed by the mutual action of the spirals of the short and thick wire upon each other; an effect which only takes place if the spirals of the wire are very near to each other; these spirals, therefore, serve at the same time as inducing body and as induced body. This current, which has been termed *extra-current* by Faraday, is produced not only when the circuit is broken, but also at the moment when it is established. Its direction is contrary to that of the current of the battery on closing, and equal to it on opening the circuit. Its energy is also notably increased by the presence of soft iron in the interior of the bobbin; it is capable of deflecting the needle of a galvanometer, it produces sparks, shocks, and heat, and will decompose water. The extra-current is due to induction by its own spirals and by the temporary magnet; the current induced in the second wire, to induction by the current of the battery and by the electro-magnet. Its direction is quite equal to that of the extra-current.

We know from the researches of an American philosopher, Mr. Henry, of Princeton, that the action of induction is not confined to two spirals; but that a current induced in the second wire may again induce another cur-

rent in a third spiral, if this be placed near to the second spiral; that the current produced in the third wire may give rise to a current in a fourth spiral, etc. Mr. Henry has also endeavoured to determine the direction of these induced currents of the second, third, and fourth order, and found that if the current induced in the second spiral be positive, that induced in the third wire would be positive again, whilst that induced in the fourth would be negative, that in the fifth positive again, etc.

The intensity of induced currents depends, in the first place, upon the intensity of the inducing current of the battery; if this be feeble, it will not be able to develop a powerful magnetism in the soft iron, and the extra current, as well as the current induced in the second wire, will be of low tension. It depends besides upon the transverse section, and the number of convolutions of the wires; the intensity of the current being directly proportional to the number of convolutions and inversely proportional to the diameter of the wire; the current will, therefore, be stronger, according to the length and fineness of the wire. Finally, the intensity of the induced current depends upon the quantity, and the more or less insulated state, of the soft iron in the centre of the bobbin.

An induced current differs from a continuous galvanic current, in the first place, by its being instantaneous. To this circumstance is due the remarkable physiological effect of the induced current, especially upon the motor nerves and muscles; as we shall see hereafter, that motor nerves and muscles are not excited by a closed circuit,

but by variations in the density of the current. On the other hand, induction currents differ from the continuous galvanic current in so far as the direction of the latter is always the same, whilst the former move alternately in different directions; indeed, we know from the deflections of the magnetized needle, that the current induced in the second wire, on closing the circuit of the battery, has a direction contrary to that of the current induced on opening it. This circumstance gives rise to a peculiarity in the chemical action of the induced current. We know that when the decomposition of water is brought about by a continuous galvanic current, the hydrogen appears invariably at the negative, and the oxygen at the positive pole. But such is not the case if we decompose water by induction currents; each wire alternately serving as the positive and as the negative pole, both hydrogen and oxygen appear at either of the poles; the gases, therefore, represent an explosive mixture, and if the induction currents succeed each other very rapidly it may even happen that both gases appearing simultaneously, and both being in the nascent state, they immediately combine again to form water, so that the water is apparently not at all decomposed by the induced current. If platinum plates be immersed in water, and induction currents be sent through them in rapid succession, the water will be decomposed and oxygen liberated; this nascent oxygen will produce oxidation of the platinum; but oxide of platinum will immediately afterwards be reduced to metallic platinum by the nascent hydrogen; thus a series of oxidations and re-

ductions takes place in the metal, in consequence of which, the platinum plates become at last covered with a black powder, which is finely-divided metallic platinum. Another very elegant experiment to show that induction currents move alternately in different directions is, to bring a solution of iodide of potassium and starch into the circuit; the blue colour indicating the liberation of iodine will then shortly appear at either of the poles, whilst if we bring about that decomposition by the continuous galvanic current, it is only at the positive pole that we notice the blue colour.

It would, therefore, appear erroneous to speak of a permanent positive and negative pole in an induction apparatus, employed for physiological or therapeutical purposes. Such is, indeed, the opinion of the author of a celebrated treatise on electricity recently published,* who explains the difference in the therapeutical and physiological action of the extra-current, which he considers as produced only on breaking the circuit, and of the current induced in the second wire, partially by the circumstance that the extra-current always moves in the same direction, whilst the current induced in the second wire alternately moves in contrary directions. But M. de la Rive seems to have disregarded the fact, that the physiological effect of the extra-current, as well as of the current induced in the second wire on *closing* the circuit, is scarcely appreciable; whilst it is very powerful on *opening* the circuit.

* A Treatise on Electricity, in Theory and Practice, by M. A. de la Rive. Translated by Charles Walker, London, 1858. Vol. III. p. 603.

We are, therefore, allowed, if we employ induction currents in physiology and therapeutics, to take into account merely the current induced on opening the circuit; which, as will be remembered, has a direction equal to that of the inducing current of the battery.

We have now considered in their principal features the phenomena of induction brought about by voltaic electricity, and proceed to take a short glance at Faraday's discovery of electric currents induced by a permanent magnet of steel. If the pole of an ordinary magnet be approached to one of the extremities of a copper wire covered with silk or gutta percha and wound in the form of a helix round a wooden cylinder, the needle of a galvanometer, communicating with the ends of this wire, is immediately seen to suffer a deflection. As long as the magnet remains in the same position, the needle is not further disturbed; but as soon as the magnet is withdrawn, we perceive another deflection of the needle, which indicates the existence of another instantaneous current produced in the wire, and moving in a direction contrary to the first. The current produced by a permanent magnet of steel is called the *magneto-electric* current, to distinguish it from the *electro-magnetic* current induced by voltaic electricity. For producing a succession of such currents, the magnet must be continually approached to, and withdrawn from, the spirals of the wires. To effect a very rapid succession, the permanent magnet is not made to act immediately upon the wires, but an armature of soft iron, having the form of a horse-shoe, is surrounded by the wires, and

set in rotation before the two poles of a fixed permanent magnet, by means of a wheel connected with an endless cord. By each turn of the wheel, the two branches of the armature are made to pass before the poles of the permanent magnet; at each passage there is magnetization and demagnetization of the soft iron, and an electric current is produced by the sudden change in the magnetic state of the armature, as well at the moment when it is approached to, as when it is withdrawn from the magnet. The intensity of the magneto-electric current depends upon the power of the permanent magnet, and upon the number of convolutions and the diameter of the wire wound round the armature of soft iron; also, on the distance of the armature from the poles of the magnet, and on the velocity with which the wheel is turned. As to the physiological effect, it is produced on breaking as well as on establishing the circuit; in the former case the effect is stronger; but the difference is not so great as that in the current induced by voltaic electricity. If, therefore, we want to avoid the continuous change in the direction, and to operate with a succession of currents all guided in the same direction, we may employ a wheel, the teeth of which are alternately of metal and ivory, so that only one of the two induced currents is collected.

Finally, a few words upon the meaning of the term "derived current." If in a closed circuit two points are connected by an additional conductor, a derivation of the current is brought about; the current, as it existed before the derivation was made, is termed the primitive current;

the additional conductor: derivation wire, and the portion of the current that passes by this wire: the derived current. It is obvious that the intensity of a derived current will always be infinitely more feeble than that of the primitive current.

III. *Animal Electricity.*

We are taught by physiology that animal life is not possible without a continuous disturbance taking place in the equilibrium of the molecules of the body; and since we know that every such disturbance is accompanied with a liberation of electricity, the existence of electric currents in the animal body during life appears a necessity.

That certain fishes, when touched, give shocks, was already known to the Romans, who employed them for the cure of headaches and gout. The best known among these fishes are the *Torpedo*, or *electric ray*, and the *Gymnotus*, or *electric eel.* The Torpedo is frequent in the Mediterranean, and has been closely studied by Davy, Savi, Matteucci, and Kölliker; the Gymnotus is to be found in Surinam,—in the ponds of Bera and Rastro,—and has chiefly become known by the graphic descriptions of Baron Alexander von Humboldt.

If an electric fish be touched on any part of its body, especially at its fins, it gives a violent shock, analogous to that yielded by a Leyden jar. In order to experience the shock, we may touch the fish either with the hand or with a good conductor of electricity, as, for instance, a metal rod; the discharges are also diffused very far in the

liquid in which the fish is contained; but if we touch the fish by glass or resin, no shock is perceived.

The electricity produced by these animals possesses all the properties of electricity, such as we develop it by artificial means; sparks may be drawn from the fish, steel needles may be magnetized, water, nitrate of silver, iodide of potassium, may be decomposed by it; and the needle of a galvanometer, when brought into the circuit, will immediately suffer a considerable deflection, so that it is easy to determine the direction of the current. The quantity of electricity liberated in these fishes is in direct proportion to the energy of circulation and respiration of the animals. After they have given numerous and powerful shocks, they require a long rest and much nourishment, to enable them to store up again a new amount of galvanic force.

The electric ray, which is generally of inconsiderable size, possesses a peculiar organ, by which the electricity is produced. This consists of small membranous prisms, packed one against the other, like the cells of a honeycomb. These prisms are divided by horizontal diaphragms into small cells, which are filled with an albuminous fluid. It is impossible not to be struck by the close resemblance between this arrangement of the electric organ, and that of the voltaic pile; indeed, the electric organ of the Torpedo constitutes a veritable voltaic pile, forming a series of solid diaphragms, positive on one of their surfaces and negative on the other; a conducting electrolytic liquid being interposed between the diaphragms.

The cells of the electric organ are traversed by numerous nervous filaments, arising from four large bundles of nerves, which take their origin from the fourth lobe of the brain, in which the electric power resides. When this lobe is irritated, very powerful discharges follow, even if the animal be to all appearance dead; that is to say, if by cutting, pinching, or squeezing it, no more shocks nor movements can be produced. When the lobe has been destroyed, the electric discharges cease soon afterwards; they cease likewise, when the connexion between the brain and the organ has been interrupted by cutting or tying up the nerves, although upon irritating the delicate nervous filaments animating this organ, electric effects may still be obtained some time after that connexion has been destroyed. The terminal branches of the nerves are very pale and slender; they anastomose in all directions, and form a very elegant and delicate network, which is destroyed by almost all the reägents that are employed in microscopical observations; the richness and density of this network has an important bearing upon the explanation of the function of the electric organ. The electric action disappears forthwith, when the albumen contained in the cells of the organ is artificially coagulated, as may be done either by boiling it, or by pouring acids upon it; but as long as the albumen remains fluid, shocks will be perceived, even if the organ be cut through.

When the Torpedo is fresh, shocks are felt wherever the animal is touched; but when it has become weary, and we then place prepared frogs upon different points of its body,

it is easy to perceive that only those frogs suffer commotions which touch that part of the skin covering the electric organ. The direction of the current is from the back to the belly of the animal; the upper surfaces of the prisms being all charged with positive electricity, the lower ones with negative electricity.

The shocks are given by the fish, either voluntarily, in order to kill animals necessary for its nourishment; or they are due to reflex action. Thus, if the fish be touched at any point of the skin, the stimulus is instantly transferred from the sentient nerves of the skin to the brain, and from the fourth lobe of the brain back to the electric organ, by way of the four bundles of nerves connecting the electric lobe with the electric organ; just as in other animals muscular contractions are produced either by the will of the animal, or by reflex action, as soon as the sentient nerves have been irritated.

The shocks given by the Gymnotus, or Surinam eel, which is from five to six feet long, are more powerful than the discharges of the Torpedo. Humboldt relates that these fishes may kill at a blow horses and mules, and that some time ago it became necessary to change the road from Uritucu through the Steppe, because the electric eels had accumulated in a rivulet in such large quantities, that year after year a great number of horses were benumbed by the shocks and drowned in the passage. If the discharge takes place through a chain of persons, all of them feel a very violent shock.

The Gymnotus possesses an electric organ like the Tor-

pedo, composed likewise of a great number of prisms similar to voltaic piles. But whilst in the Torpedo the direction of the current is from the back to the belly, in the Surinam eel it is from the head to the tail; positive electricity being accumulated at the anterior part, and negative electricity at the posterior part of the body. If the animal be touched at the head and the middle of the body, or at the tail and the middle of the body, the shock has only half the intensity of that experienced when both head and tail are touched.

In the Torpedo there are 940 series of diaphragms, each separate series containing 2000 diaphragms; in the Gymnotus there are only 96 series of diaphragms, each containing 4000 diaphragms. We have, therefore, 1,880,000 diaphragms in the Torpedo, and only 384,000 in the Gymnotus. Nevertheless the shocks given by the latter are much more powerful than the discharges of the former; which is due to the larger surface presented by the diaphragms of the electric organ of the Surinam eel. Its electric power resides likewise in the brain, as is proved by the researches of Baron Humboldt; it is much to be regretted that circumstances did not allow him to inquire whether it is also seated in a particular lobe of the brain; as in the Torpedo.

The electric currents circulating in other animals are not so easily to be perceived as those produced by the electric fishes; but we have reason to believe that there exists a vast multitude of well-determined electric currents, both in the nerves and in the muscles of all living ani-

mals, which have for the most part only local circuits; that the presence of these currents is not due to any physical or chemical action, but is subordinate to the life of the animal, and that the currents disappear soon after life has become extinct.

It is very difficult to make conclusive experiments of the kind, because the currents which we may collect, are merely derived currents, the intensity of which is infinitely more feeble than that of the principal nervous or muscular current; in fact, the electro-motive elements in the nerves, as well as in the muscles, must be considered as in the condition of a closed circuit, and every current *collected* from a nerve as *derived* from a current circulating in the nerve itself. Besides, it is absolutely necessary to avoid any liberation of electricity arising from other sources than from the animal body itself. For these researches the nerves and muscles of the frog are usually employed, as they retain their irritability very long, whilst warm-blooded animals lose it rapidly after death.

Galvani was the first who proved by experiments the existence of electric currents in a frog, which he had prepared in a peculiar manner. He killed the animal, then rapidly skinned it, and passed the point of a pair of scissors beneath the two lumbar nerves, which appear like white threads on each side of the vertebral column. He then removed the second and third lower vertebræ, so that the lumbar nerves were laid bare, and now formed the only link between the hinder extremities of the frog and its upper vertebræ. He then connected the nerves

and muscles of the frog by means of an arc composed of two metals, and immediately perceived powerful contractions of the muscles. Volta objected to this experiment, that the electric current thus liberated was due to the contact of the two heterogeneous metals. Galvani therefore connected the nerves and muscles by means of an arc of homogeneous metal, and even thus produced contractions. But Volta contended that any difference, however slight, in the homogeneity of conducting bodies in contact was sufficient to produce an electric current made perceivable by the contractions of the frog. Galvani then cut the nerves of a frog at their exit from the vertebral canal, raised them with a glass rod, so as to bring them in contact with the external surface of a frog's thigh, on a single point of the muscle, and the muscles contracted as before. Volta now tried to prove that the electric current thus produced had its source in the contact of nerve and muscle; but Galvani succeeded at last in bringing about contractions, by merely connecting the nerves of two thighs, so that there was no contact between heterogeneous bodies. This contraction was denied by Volta, but maintained by Baron Humboldt, whose researches on the irritated muscular and nervous fibres were published in 1797.

Nevertheless Volta's views were generally accepted by natural philosophers, and it was not until thirty years later that Galvani's and Humboldt's experiments were again taken up by M. Nobili, of Reggio, and, employing for his researches a sensitive galvanometer multiplier, suc-

ceeded in showing undeniably the existence of an electric current in the frog, which he believed to be proper to the frog. The magnetized needle was deviated to 30° by this current, moving in the direction from the muscles to the nerves; its action on the multiplier was not unfrequently seen to last for several hours. Nobili found that if he touched the nerve and the muscle of one frog, with the nerve and the muscle of another frog, there was no effect on the magnetized needle, one current being opposed to the other; but if he placed the nerve of one frog in contact with the muscle of another frog, a powerful contraction took place.

These researches were further pursued by Matteucci, but it was a German philosopher, Du Bois Reymond,* who devised the most ingenious and unobjectionable method of investigating this matter; by means of which he was enabled notably to enlarge our knowledge on the interesting phenomena of animal electricity. His views are now universally received by the Profession.

For demonstrating the electric properties of nerves and muscles, Du Bois Reymond chose a galvanometer multiplier brought to the highest degree of sensitiveness, and the physiological galvanoscope, or galvanoscopic frog.

The multiplier is made very sensitive, partly by employing astatic needles of the utmost possible perfection, and partly by a very great number of convolutions of the wire. A multiplier possessing less than 11,000 turns of a fine copper wire is not applicable for investigating the current proper of the nerves; for demonstrating the mus-

* Untersuchungen über thierische Elektricität. Berlin, 1848 and 1849.

cular current in the living man, a multiplier of 24,000 convolutions is necessary. This multiplier indicates not only the presence and direction of very feeble electric currents, but also certain changes in their intensity. There is, however, the inconvenience that the magnetized needle is too slow to indicate a current of an instantaneous duration; that it is not able to follow all the variations in the intensity of the current which sometimes succeed each other very rapidly; indeed, it will only tell the resultant of such variations. Therefore, it is necessary to have another indicator of the current; this is the galvanoscopic frog, or the rheoscopic limb, which is prepared in the following way. A frog is killed, then rapidly skinned, and its thigh-bone cut off just above the insertion of the gastrocnemian muscle; after this has been done, all the muscles by which communication is kept up between the upper and lower piece of the thigh are removed, and the sciatic nerve is prepared as high up as possible towards its origin, and afterwards cut at its upper end, so as to remain in connexion with the leg. The galvanoscopic frog thus prepared indicates the presence of currents of instantaneous duration, without the intervention of metals, even when the currents move in contrary directions, and succeed each other very rapidly. It has, however, the disadvantage that it soon loses its irritability, and that it contracts only when the circuit is made or broken, but not while the circuit remains closed, so that it does not help us to decide whether there is a continuous current, or a momentary discharge. It is, therefore, obvious, that

both the multiplier and the galvanoscopic frog are equally necessary, if we investigate the phenomena of animal electricity.

It is of paramount importance to avoid bringing into the circuit any heterogeneous substances, which might possibly give rise to a liberation of electricity. Consequently, both extremities of the wire of the multiplier are connected with platinum plates, which must be as heterogeneous as possible; as the slightest difference between the two platinum plates would of itself cause a current if the circuit were closed, and the plates dipped into a vessel filled with water. To render the platinum plates quite similar to each other, Du Bois Reymond first cleans them with a mixture of alcohol and ether; he then washes them with nitro-muriatic acid, and afterwards with distilled water, and he finally heats them to incandescence for half a minute, by means of a Berzelius lamp. The plates are held in a clamp fixed on a horizontal brass rod, which can be fixed and moved in every position; the free extremities of the plates are then immersed in two large vessels filled with a saturated solution of common salt. But we are not allowed to immerse the animal parts directly in the salt water, since this would exercise an injurious action upon the tissues; Du Bois Reymond, therefore, uses two cushions made of many layers of fine blotting paper, well moistened with salt water; these are immersed with one of their extremities into the liquid, and rested against the edge of the vessel; their free extremities are outside of the vessel, and the circuit is closed by connecting the two

conducting cushions by a third cushion. To avoid the corroding action of the salt water upon the animal tissues, a piece of bladder well moistened with the white of a fowl's egg is laid upon each cushion.

If we have thus arranged the multiplier, and now take a fresh piece of the sciatic nerve of a frog, and bring various parts of it in connexion with the two cushions, we notice the following phenomena: if any two symmetrical parts of the longitudinal or of the transverse section of the nerve are placed upon the cushions, there is no deflection of the needle; if two dissymmetrical points of the longitudinal section are taken, we obtain a feeble deflection of the needle, varying from 6° to 7°; and if the nerve be in contact with the cushions on one side by its longitudinal section, and on the other by its tranverse section, the needle suffers a deflection, varying from 15° to 30°. The current thus indicated moves from the longitudinal section of the nerve through the galvanometer wire to the transverse section of the nerve; and the points which are nearest to the middle of the nervous fragment are positive in respect to those which are nearer to the extremities. The results are the same if we employ the galvanoscopic frog; and whether we employ nerves of sensation or of motion, or mixed nerves, or pieces taken from the spinal cord; as to the brain, every artificial section of it is negative to every point of its natural surface.

Remarkable changes are produced in the intensity of the nervous current, if a part of the living and excitable nerve of a frog be subjected to the action of a continuous

galvanic current, another part of the same nerve being placed upon the cushions. The intensity of the nervous current is increased, if the galvanic current, which is made to act upon the nerve, moves in the same direction with the nervous current (*positive phase of the nerve;*) on the other hand, it is diminished, if the direction of the galvanic current be opposed to that of the nervous current (*negative phase of the nerve.*) The alteration thus produced in the nervous current has been termed by Du Bois Reymond the *electro-tonic state.* This state commences as soon as the circuit of the battery is closed; it then remains unchanged all the time that the galvanic current continues to circulate in the nerve, and disappears immediately when the circuit is opened again. The electro-tonic state is not due merely to the transmission of the galvanic current through the nerve, but to a real alteration in the electrical properties of the nerve; for the electro-tonic state is not induced if a wet thread be interposed between the two parts of the nerve, and tightly drawn together; since now both parts are no longer connected by nervous matter, but only by the neurilemma and the wet thread, which oppose no resistance to the transmission of the galvanic current. Besides, the electro-tonic state is not induced, if the nerve has lost its excitability. From these facts Du Bois Reymond has concluded that the nerves consist of an innumerable multitude of electrical molecules, which are differently arranged according to the different states of the nerves. Indeed, the electric currents in the nerves show, in some instances, variations both of inten-

sity and of direction, so sudden, that it appears impossible to account for them by any change of larger heterogeneous elements, or in any other way than by assuming corresponding changes of position in almost infinitely small centres of action. When the living nerve is at rest, Du Bois supposes these molecules being turned towards each other with equal extremities, so that two molecules form, as it were, only one molecule, possessed of one positive zone, and two negative poles. This he calls the *peripolar arrangement.* In the electro-tonic state, however, the molecules are thus arranged, that unequal poles are turned toward each other; this he terms the *dipolar arrangement.*

There are other important changes induced in the nervous current, as soon as the nerve enters that active state which enables it to cause motion, sensation, and secretion, whatever may be the means by which the nerve is excited; to demonstrate this, we may tetanize the nerve by strychnia, or excite it by burning, or by bruising the free extremity, which is placed between the cushions. When this has been done, the needle, which had been deflected by the nervous current during the peripolar arrangement, returns immediately more or less towards its previous position of equilibrium; that is to say, the nervous current suffers a sudden and great diminution, which is called by Du Bois the *negative variation of the current.* This lasts only as long as the nerve is kept in an excited state; if it be no longer excited, the previous effects of the nervous current reäppear again. The negative varia-

tion of the current, however, is not permanent, even when the contraction seems to be so, as in the state of tetanus; but, like the contraction, it is always composed of a very rapid succession of single and sudden variations.

When the nerve is no longer able to cause motion, sensation, secretion, the nervous current appears very feeble, or its original direction becomes inverted, the negative surfaces being now positive, and the positive surfaces negative. If we now try again to cause the electrical phenomena inherent to the living nerve, we may perhaps succeed in producing the electro-tonic state in a trifling degree, but we shall always fail to induce the negative variation of the current. Besides, the electro-tonic state ceases so shortly after the cessation of the excitability of the nerve, that we may just as well contend, that all the electrical phenomena in the nerve disappear at the same time with its vitality.

For investigating the electric properties of the muscles, Du Bois Reymond chose likewise the multiplier and the galvanoscopic frog. But as the muscles produce currents of far greater intensity than the nerves, the multiplier must not possess so many convolutions as that intended for demonstrating the nervous current (4000 to 6000 instead of 24,000.) The muscular current appears to be perfectly analogous to the nervous current, except that it is more intense. We do not perceive a deflection of the magnetized needle, if the muscle is placed upon the cushions with two symmetrical points, whether of the longitudinal or of the transverse section; the more dis-

symmetrical the two points, the stronger will be the deflection of the needle; the current is strongest when a portion of the fleshy surface of the muscle is laid upon one of the cushions, and a portion of the surface formed by cutting the muscles across, upon the other; that is to say, between the natural longitudinal section and the artificial transverse section,* whilst the current is very feeble between any two points in the same section, whether longitudinal or transverse.

The direction of the muscular current is the same as that of the nervous current. In the living muscle each point of the longitudinal section, whether natural or artificial, is positive in respect to the points of the transverse section, whether natural or artificial. Each time that a conducting arch is established between any point of the longitudinal section of the living muscle, and any point of its transverse section, the needle indicates a current in this arch, moving from the longitudinal section to the transverse section. This law has been established on the muscles of the frog, and verified on the muscles of an amputated leg of a man, on the muscles of rabbits, mice, sparrows, and even of the common earth-worm; it has been verified not only with an entire muscle, but with a single primitive fasciculus; indeed, we may obtain a deflection

* The tendinous portion of the muscle is its natural transverse section; the fleshy surface of the muscle is its natural longitudinal section; its artificial transverse section is produced if the muscle be divided perpendicularly; and an artificial longitudinal section, if the muscle be torn in the direction of its fibres. The nerves have no natural transverse section, and, therefore, their electro-motive power, when they are in the state of rest, cannot be made apparent unless they have been previously divided.

of 8° to 10° by means of a single elementary bundle, so placed as to connect the transverse and the longitudinal section of a muscle.

The variations in the intensity and direction of the muscular current are, in certain instances, so sudden and so extensive, that we are compelled to assume corresponding changes of position in the molecules of the muscle, which are analogous to those supposed to be in the molecules of the nerves.

It is much more difficult to demonstrate the muscular current in man than in the muscles of a frog. We know, however, that the current in the arm of man travels from the shoulder to the hand, whilst in the frog it travels in a contrary direction. It is especially the resistance offered by the skin of the human body that diminishes the action on the magnetized needle. The deflections of the needle become much more considerable as soon as the cuticle is removed, or the portion of the body subjected to the experiment is placed in communication with the salt water that closes the circuit. To prove the existence of the muscular current in man, a multiplier of 27,000 to 30,000 convolutions is required. Besides, we must avoid getting electric currents arising from other sources, as from the unequal transpiration of the skin on two points placed in connexion with the multiplier; from inequality of temperature, from the want of simultaneity in the establishment of the contact of the two points placed in the circuit, etc. The intensity of the current produced by the voluntary contraction of the muscles of man may be considerably increased if we remove the cuticle by means of blister

applied to the arm, and place these artificial wounds in communication with the multiplier. By experimenting in this way, Du Bois Reymond obtained a current of 60° to 70°, whilst, if the skin in its usual state communicated with the multiplier, the deflection of the needle was only 2° to 3°. From this we may again infer, that it is the cuticle which offers the most powerful resistance to the manifestation of the currents circulating in the human body.

An analogous phenomenon is observed in the frog. If this animal has been skinned, it is very easy to demonstrate its muscular current; but if the skin be left intact upon the muscles, we get irregular results, which are perhaps partly due to the circumstance that the skin possesses an electro-motive force proper. If we want to show the muscular current in all its intensity, the surface of the muscle must be moistened with salt water. As long as a tendon of a fresh muscle is touched merely by blood or lymph, the current going from the longitudinal section to the transverse section is very feeble. Its intensity is immediately increased if the tendon be immersed in any other liquid; it is likewise increased if the tendon be totally taken away or destroyed by the contact of a piece of porcelain highly heated. Hence it results, that the fresh muscle, as long as it is touched only with blood and lymph, possesses a superficial layer, which more or less prevents the manifestation of the contrast between longitudinal and transverse section. Du Bois Reymond has, therefore, termed it the *parelectronomic layer.*

The parelectronomic layer exists in different proportions in different animals. It is most complete in frogs, which have been for some time subjected to the temperature of melting ice; on the muscles of these animals there is either no current at all, or an inverse current, due to the predomination of the parelectronomic layer. But even under these circumstances, the current is instantly revivified, if the tendon has been touched for a short time by water, albumen, alcohol, acids, alkalies, or salt water. The muscles of mammalia, birds, and fishes, present the same property, although in a less degree.

Finally, a few words on the phenomenon comprehended under the name of *induced or secondary contraction*, which was first observed by Matteucci. He prepared a frog in the manner originally devised by Galvani, and placed upon the thighs of the frog the nervous filament of another rheoscopic limb, uniting both, as it were, by a bridge. He then caused a continuous current to pass into the lumbar nerves of the first frog, and brought about a powerful contraction, not only in the muscles of these thighs, but at the same time in the galvanoscopic frog, the nerve alone of which was in contact with the thighs of the first frog, which were being directly excited by the electric current. Du Bois Reymond succeeded in inducing a contraction of the third, fourth, and fifth order, in rheoscopic limbs, which communicated with each other merely by the nerves. These induced or secondary contractions are due to variations of the density of the current in the rheoscopic limb. No effect, however, is ob-

tained, if the nerves be made to communicate with two points symmetrically situated in the muscle; if we want to produce secondary contractions, it is necessary that the two points of the nerve of that limb, which is to suffer a commotion, should be laid upon such points of the muscle in contraction, which are as dissymmetrical as possible.

The diminution in the intensity of the muscular current after death is proportional to the degree of excitability possessed by the muscles. It is therefore more rapidly diminished in warm-blooded animals than in reptiles and fishes. As soon as *rigor mortis* sets in—probably in consequence of the coagulation of the fibrine contained in the muscles outside of the blood-vessels—both the excitability of the muscles and their electro-motive force disappear, never to appear again, not even when the rigidity has ceased in consequence of the decomposition of the fibrine. Therefore, the phenomenon of the muscular current is inherent to the living and excitable animal tissue.

It is not only the nerves and muscles, the brain and the spinal cord of the living animal, that are possessed of electro-motive force, but all tissues in which active nutrition is going on give rise to electric currents. Pieces of lung, liver, and kidney, cause weak currents, which partially obey the laws of the muscular current, and which continue long after death. In no other tissue, however, is the electro-motive force so strong, nor are there so great and sudden variations in the intensity and direction of the current, as in the nerves and the muscles.

In fact, the electrical properties of tissues, are in direct proportion to the activity with which the general metamorphosis of matter is being carried on in them. Electricity is everywhere manifested where there is a disturbance going on in the equilibrium of molecules; and the more rapidly and extensively this equilibrium is disturbed, the more striking will be the manifestations of electricity. But we must take care not to confound the true animal electricity, which is a vital phenomenon, with electric currents that arise merely from chemical action, and may be observed as well in dead as in living animals, and in vessels filled with heterogeneous liquids, as well as in the animal body. I here allude particularly to the so-called *gastro-hepatic current*, which was discovered in 1834, by Matteucci, and which has attracted considerable notice ever since; a few words on it may not be out of place here.

In 1833, Matteucci published a paper, in which he stated that metal salts, when brought into the blood, were decomposed; the acids being attracted and excreted by the kidneys as electro-positive organ, the alkalies by the liver as electro-negative organ. He also mentioned that an electric current was obtained, if the two ends of a pneumogastric nerve, which had been cut, were connected by means of the platinum extremities of a multiplier. The latter assertion, however, was soon afterwards withdrawn by Matteucci. In 1834, Professor Donné published a paper in the Annales des Sciences Naturelles, in which he stated that, if equal extremities of the multiplier

were brought into contact with chemically dissimilar organs of secretion (as, for instance, the skin and the mucous membrane of the mouth, or the liver and the stomach,) considerable deflections of the magnetized needle were observed. Matteucci now asserted, that these currents resulted from the contrary electric states of the organs of secretion, which were the cause of the chemical dissimilarity. To prove the existence of a current moving from the stomach to the liver, Matteucci introduced a plate of platinum into the stomach of a living rabbit; he then placed another plate on the liver, and connected both of them with the extremities of a galvanometer; and he found that the needles instantly traversed an arc of 20°, thus proving the existence of a powerful current between the liver and the stomach. He now tried to decide the question whether this current ought to be considered as the effect or the cause of the chemical differences alluded to, since it is generally known that an electric current is developed, if an alkaline and an acid liquid be separated by permeable structures; and the stomach contains an acid, the liver an alkaline secretion. In order to arrive at a satisfactory result, he divided, he says, the nerves and vessels passing into the abdomen above the diaphragm, and observed, that in an instant the needle of the galvanometer deviated to 3° or 4°, instead of 20°; and after he had cut off the head of the rabbit, hardly any deflection was to be obtained. But if a wire was thrust into the spinal cord, and thus lively contractions were produced, the gastro-hepatic cur-

rent was temporarily re-established.* From these experiments Matteucci concluded that the gastro-hepatic current was not the effect, but the cause, of the chemical metamorphosis of the saline ingesta, the decomposition of which furnished acid to the stomach, and alkali to the liver; that it was not yet known how this current was excited, but that the existence was definitely proved of an electric current between the stomach and the liver, which would nearly cease on division of the nerves, and completely vanish with the death of the animals. This current should be competent to the evolution of sufficient free acid in the stomach, to enable digestion to go on, an equivalent of soda being determined to the liver.

Both the experiments and conclusions of Matteucci were soon afterwards proved to be completely erroneous by Donné, who showed by experiments made on twelve rabbits that the so-called gastro-hepatic current may be observed on dead as well as on living animals; from the liver of one rabbit to the stomach of another, and *vice versâ;* that neither the section of nerves and vessels, nor the cutting off the head, nor the excitation of the spinal cord, whether mechanical or electrical, has any influence whatever on the intensity of the current; and, finally, that unequal organs, cut out of the body and held in the hands, continue to give rise to electric currents; that, in fact, the so-called gastro-hepatic current is only

* Matteucci has omitted to mention how it happened that if the cord was excited in this manner, the excitation was transmitted from the cord to the liver and stomach, *after all the connecting nerves had been cut off.*

an artificial electro-chemical phenomenon, and has nothing whatever to do with animal electricity. As these experiments of Donné were published as far back as 1834, it is to be regretted that the hasty conclusions drawn by Matteucci from experiments not over-cautiously conducted, have been maintained as correct, not only in the lectures on electricity and galvanism which were delivered by Dr. Golding Bird, before the Royal College of Physicians, in 1847, but also in a widely-circulated treatise on human physiology, which bears the date of 1855.

CHAPTER II.

ELECTRO-PHYSIOLOGY.

I NOW intend describing the physiological effects produced by the application of electricity to the different tissues of the living body in their normal condition. I shall successively pass in review the action of electricity upon the brain and the spinal cord, the organs of sense, the sentient nerves, the motor nerves and the muscles, the sympathetic nerve, the contractile fibre-cells, the heart, the blood, the skin, and the bones. A thorough knowledge of these effects will enable us to form more accurate notions of the value of electricity in its application to disease, than might otherwise be obtained.

The physiological effects of electricity are partly dependent upon the electricity itself, and partly upon the property and function of the organ that is submitted to the action of electricity. In the first instance, the *form* of electricity which is used is of great importance. Thus, if *sparks* from the common electrical machine are applied to the skin, they produce a sensation of pricking and pain; if they are large, the skin will become red, and a

papular eruption, resembling the lichen urticatus, will be produced. If a *continuous current* of galvanic electricity is made to act upon the skin, a sensation of heat, redness, inflammation, ulceration, and destruction of the skin and the subjacent structures, are produced. An *interrupted* electro-magnetic current will cause sensations, varying, according to the intensity of the current, from simple tickling to an acute burning pain; but, although the tension of the current may be very high, it will not produce an inflammation, or gangrene, like the continuous current. To give another instance, if *sparks* from the common electrical machine are applied to the face, they produce a sensation of light which is, however, not very distinct; if the *continuous* current be applied to the face, a remarkable flash of light is perceived by the one subjected to the experiment, and if the current has a certain intensity, it tends to over-excite the retina, so as to cause instantaneous blindness. If an *induced* current be applied to the face by means of moist conductors, it produces no sensation of light, but contractions of the muscles of the face and a variety of physiognomical expressions; the retina is only excited by the induced current, if it possesses a very high tension.

Besides the form, the *quantity* and *intensity* of the electricity have an important bearing on the production of the physiological effects. If a large quantity of electricity is used (as is the case if we employ a voltaic pile) remarkable calorific and chemical effects are produced, viz.: a very strong burning pain and cauterization and

destruction of tissues. If an induced current of low tension is employed, such as is produced in a short and thick wire, feeble contractions of the muscles are produced, but it does not much affect the sentient nerves; on the other hand, an induced current of high tension, as is produced in a long and fine wire, causes not only muscular contractions, but also strong sensations; and if the intensity of the current be very high, pain is excited which surpasses that produced by the application of red-hot iron; and muscular contractions, resembling those violent cramps which are observed in persons poisoned by strychnia.

The physiological effects caused by electricity are also different according to the mode in which electricity is transmitted to the organs. An induced currrent, applied to the skin by moist conductors, produces contractions of those muscles which are beneath that part of the skin to which the electrodes are directed. If dry metallic conductors are used, there will be an effect on the sentient nerves of the skin, but not on the contractile power of the muscles; provided that the tension of the current is not very high. If the electrodes are firmly pressed against the skin, at a point where a motor nerve is superficial, contractions of all the muscles take place which are animated by that nerve; but if the conductors are not pressed against the skin, the current will run along the cellular tissue which envelops the nerve (as cellular tissue is a better conductor of electricity than the nerve,) and therefore in the latter case no muscular contractions are produced.

The physiological effects of electricity are further determined by the special property of the organ to which electricity is applied. The same electric current which produces a flash of light when applied to the eye, causes a special sensation of taste when directed to the tongue; sounds, when applied to the ears; muscular contractions, when directed to a motor nerve, and sensations of heat when applied to any part of the skin. Finally, the different states of vitality of the organ, at the time that the electricity is applied to it, are of great importance. Thus a morbid increase of sensibility in a nerve, as we observe in sciatica, tic douloureux, and other forms of neuralgia, may be subdued by electricity; on the other hand, a nerve, the vital energy of which is gone, or materially diminished, may by electricity be restored to its normal condition.

I. *Action of the electric current upon the brain.*

The action of the induced current upon the brain of living animals has been investigated by Professor Weber.* No effect is to be observed if the electrodes are applied to the hemispheres of the brain, or to the cerebellum; not even if they are thrust into the medullary substance; but by galvanization of the tubercula quadrigemina, irregular convulsions are produced, which very much resemble the clonic cramps, such as are observed in patients suffering from certain diseases of the brain; or they resem-

* Article Muskelbewegung, in Wagner's Handwörterbuch der Physiologie. Vol. iii. part 2.

ble reflex movements, that is to say, they do not appear irregularly in all the muscles, but in certain groups of muscles which are naturally combined in action. If the medulla oblongata be excited, tetanic convulsions are the consequence, which resemble those observed in persons poisoned by strychnia. Prof. Weber thought we might infer from this, that if clonic cramps are observed in patients, there is a disease of the brain; whilst there would be a disease of the medulla oblongata, or the spinal cord, if tonic cramps are observed; but these conclusions have, up to the present time, not been entirely justified by clinical experience. Another phenomenon observed after the galvanization of the medulla oblongata is stoppage of the action of the heart.

Matteucci has made some experiments on the action of the continuous current upon the brain of living animals.* He observed that when the poles of a pile of sixty pairs were applied to the hemispheres of the brain, the animal did not start; nor was any effect visible if the cerebellum was touched, but when the electrodes were directed to the tubercula quadrigemina, and the crura cerebri, the animal began to scream, and at the same time all the muscles of the body were contracted. These phenomena lasted for several seconds, but were not observed at the cessation of the current.

It would be interesting to investigate by experimental researches the action of a closed continuous current upon the brain of living animals. From what we know

* Traité des phénomènes électro-physiologiques des animaux. Paris, 1844, p. 242.

about the effect of the closed circuit on the spinal cord and the motor nerves, it is probable that a continuous current applied to the tubercula quadrigemina, and the crura cerebri, would exercise a paralyzing influence, and tend to counterbalance any mechanical or electrical stimulus directed to those parts of the brain.

II. *Action of the electric current upon the spinal cord.*

Professor Weber has observed that, if an induced current is applied to the spinal cord, one electrode being directed to the upper, and the other one to the lower, extremity of the cord, all the muscles of the trunk and of the extremities are shaken by tetanic convulsions. The same is observed if one electrode is placed at the anterior, and the other one at the posterior, wall of the upper part of the cord; and likewise when both electrodes are applied to the lower part of the cord, provided that the integrity of the cord has not been destroyed. Hence it results that the cord is the nervous centre for all the muscles of the trunk and of the extremities. If the cord were only the common trunk of all the motor nerves emerging from the vertebral canal, galvanization of the lower part of the cord would only produce a convulsion of the hinder extremities, but not of all four extremities. If, however, the spinal cord is cut in two halves, and the lower half is then galvanized, only the muscles of the hinder extremities enter into contraction; even if both parts of the cord are made to touch each other closely at those points where the section has been made (so that

there is no impediment to the passage of the electric current to the upper part of the cord,) the muscles of the upper extremities remain perfectly quiet. From this we may infer that the convulsions described are not produced because the electric current is transmitted from the cord to the motor nerves, but because the passage of the electric current excites the action proper of the cord, which in its turn excites the property of the motor nerves to produce commotions of the muscles. It is also worth mentioning, that the tetanic convulsions produced in the extremities by galvanization of the cord, continue for a certain time, say half a minute, after the cessation of the current; while, if the anterior roots, or the mixed nerves are excited, the commotions disappear immediately after the circuit has been broken.

If the spinal cord be subjected to the action of a closed continuous circuit, convulsions of the extremities are produced at the commencement of the current; but if the current continues to traverse the cord, a paralyzing effect takes place, whatever may be the point to which the poles are directed. As long as the cord is traversed by the continuous current, it remains insensible to a stimulus which may be applied to it. Thus we may prick the cord by a pin or excite it by an induced current, and the extremities will nevertheless remain perfectly quiet; but at the cessation of the continuous current, mechanical or electrical excitation of the cord will again give rise to tetanic convulsions of the limbs. It was first pointed out

by Baierlacher* that this diminution of excitability is confined to the spinal cord, and does not extend to the motor nerves and muscles; for if an induced current is applied to the motor nerves of the hinder extremities, while at the same time the cord is being traversed by a continuous current, commotions are produced in these muscles, the nerves of which may be submitted to the action of the interrupted current. The inverse continuous current is more powerful in paralyzing the spinal cord than the direct current.

Professors Budge and Waller have observed, that the pupil becomes dilated, if that part of the spinal cord, which is situated between the seventh cervical and the sixth dorsal vertebræ, is galvanized; this part of the cord has, therefore, been termed by them the *cilio-spinal region.* If this part of the cord be galvanized, the excitation is transmitted to the cervical sympathetic nerve, which takes its rise from that part of the cord, and which animates the radiar fibres of the iris (musculus dilatator.) These fibres contract energetically, if the cervical sympathetic nerve be excited, and counterbalance the action of the circular fibres of the iris (musculus constrictor;) thus dilatation of the pupil must ensue. After the section of the sympathetic nerve the pupil becomes constricted, as by such an operation the radiar fibres of the iris are paralyzed, while the circular fibres remain in their normal connection with the nerves.

* Die Inductions-Elektricität, Nürnberg, 1857, p. 102.

III. *Action of the electric current upon the organs of sense.*

All the different forms of electricity are capable of exciting the nerves of the organs of sense; the effect, however, is much more remarkable, if we employ the continuous current than if frictional electricity or the induced current is used. If the induced current be employed, differences are to be observed according as we use the current induced by voltaic electricity or the current induced by a permanent magnet of steel; when both are of the same intensity, the magneto-electric current will have more effect on the organs of sense, and more especially upon the retina, than the electro-magnetic current; which is probably due to the circumstance, that the variations of the magneto-electric current are not so sudden and considerable as those of the current induced by voltaic electricity. If we use the interrupted current for exciting the retina, it must possess a high tension, or no effect would be produced; therefore the current induced in a long and fine wire (induced current, properly so called, or Duchenne's current of the second order) will best answer our purpose. In regard to the direction of the current, I may mention that the *positive* pole acts much more on the retina and on the tongue than the negative pole; but if an electric current is applied to the ear, the effect will be stronger if the *negative* pole be applied to it.

1. *Organ of vision.*

If the continuous current of a single pair is caused to

act upon the optic nerve, one of the metals being placed to the conjunctiva or to the eyelid well moistened, and the other metal to the other eye or eyelid, a flash of light is perceived, which is strongest at the commencement of the current; while the circuit is closed, the luminous appearances are much less intense, but they become more distinct again when the circuit is broken. I need not mention, that this is no real development of light, but that the flash is only seen by the one subjected to the experiment, in consequence of the vital energy of the optic nerve being excited by galvanism.

Sparks taken from the common electrical machine and applied to the eyes, produce also luminous appearances, though not very distinct. If we take care to interrupt the current of a galvanic battery by means of a cut-current or rheotome; or if we use the induced current, the effect on the retina will be much less considerable than if the continuous current be used. The extra current of an induction machine, which is produced in a short and thick wire, and possesses, therefore, a low tension, does not affect the retina in the least degree; it can consequently be used without danger in the paralysis of the portio dura, for exciting the paralyzed muscles of the face; on the contrary, we must avoid in this affection the application of the continuous current and of the current induced in a long and fine wire, as thereby the vision of the patient might be endangered.

The flash of light perceived in consequence of the galvanic excitation of the retina appears coloured; it is blu-

ish, when the positive pole is applied nearest to the eye; and Ruete observed that, in this case, the sensation of light is strongest at a point which corresponds to the macula lutea, becoming gradually darker as it approaches the periphery of the field, while if the negative pole is directed to the eye, a yellow-reddish or orange-coloured light is perceived, which appears strongest in the periphery of the field, and gradually darkens towards the centre.

The luminous appearances take place by reflex action from the sentient fibres of the trigeminal nerve to the retina. They may therefore be perceived, whatever the position of the poles, provided that one of them touches a point of the skin or a mucous membrane animated by a filament of the fifth pair. It is, therefore, unnecessary to touch one or both eyeballs or eyelids; we may perceive the flash, for instance, if one pole be directed to the Schneiderian membrane, and the other to the mucous membrane of the cavity of the mouth. Mr. George Hunter observed, that by placing one of the metals as high up as possible between the gums and the upper lip, and the other in a similar situation with respect to the lower lip, a flash was produced as vivid as that occasioned by passing one of the metals up the nose and placing the other upon the tongue.* It differs, however, from the flash produced in any other way by the singular circum-

* Experiments and Observations relative to the Influence lately discovered by M. Galvani, and commonly called Animal Electricity. By Richard Fowler. Edinburgh, 1793, p. 64.

stance of not being confined to the eye alone, but appearing diffused over the whole of the face. The flash may be also perceived, if one pole is placed in the mouth and the other in the rectum; this experiment was first made by M. Achard, of Berlin.*

The flash becomes more distinct and of a stronger colour on darkening the room, and Humboldt relates that, during storms, the effect of galvanism upon the eyes is most remarkable. I may also mention that Fowler made the experiment on himself at a time when one of his eyes was inflamed, and noticed that the flash produced in the inflamed eye was much more considerable than in the uninflamed eye. On the other hand Humboldt states that he made the experiment when he was affected by a very bad cold; and that then he was not able to perceive the flash at all, even if he made use of an otherwise most efficacious arrangement of the metals.

The intensity of the flash is directly proportional to the intensity of the current employed, and inversely proportional to the resistance offered to the passage of the current. A flash is produced by a very feeble current, such as is excited by a half crown piece and a penny; it is more distinct if, instead of copper and silver, tinfoil and silver, or zinc and gold, are used. The excitation of the retina produced by a pile consisting of a number of pairs, is very violent, and instantaneous blindness may ensue from it. Duchenne, who was unacquainted with the

* Versuche über die gereizte Muskel und Nervenfaser. Von Alexander von Humboldt. Posen und Berlin, 1797, vol. i. p. 334.

power of the continuous current to excite the retina in this remarkable manner, relates a case, which fully proves the practical importance of the knowledge of the physiological effects which electricity will invariably produce. He galvanized a patient suffering from paralysis of the portio dura, at first by the interrupted current, and afterwards by the continuous current of a pile. Immediately after the electrodes of the pile had been applied to the face, the patient exclaimed that he saw the whole room in a blaze; he afterwards complained of having lost his sight on that side where the electrodes had been applied; and he never regained it. Duchenne claims for himself the discovery of the special action of galvanism on the retina; but this was already known to Volta, before the commencement of the present century.

If the resistance to the passage of the current be great, the flash perceived in consequence of the galvanic excitation of the retina will be very feeble. Thus, if the two metals are applied to the face at two points where the skin is quite dry, the flash will be incomparably less vivid than if the skin be previously moistened. Besides, the flash will be stronger if the electrodes are directed to the conjunctiva, or to the Schneiderian membrane, or to the mucous membrane of the cavity of the mouth, than if they are applied to the skin of the face; since the delicate epithelium of the mucous membranes offers much less resistance to the passage of the current than the epidermis.

2. *Organ of smell.*

It is a well-known fact that frictional electricity gives rise to a peculiar smell, which is not exactly that of phosphorus, but half sulphurous and half phosphoric. It was formerly believed that this odour was due to a peculiar state of the olfactory nerve excited by electricity; but we now know, from the researches of Professor Schönbein and others, that the odour arises from the presence in the air of ozone, which is an allotropic modification of oxygen due to electricity. Oxygen is modified by electricity, just as are other substances, phosphorus, sulphur, etc., by heat; it differs from common oxygen especially by the particular odour just mentioned, and by an exaltation of its chemical affinities; thus ozone tends to change silver into oxide of silver, to decompose iodide of potassium and other salts.* The odour of ozone is hardly ever perceived near voltaic piles and induction machines; this is due to the circumstance that voltaic as well as induction sparks are always accompanied with a development of heat, by which ozone is destroyed as soon as liberated.

Neither the common electric sparks, nor the continuous, nor the interrupted current (if they are not of great

* The properties of ozone are the same, whether it be derived from the action of the electric machine, from atmospheric electricity, or from chemical action. Ozone is chemically prepared by placing a piece of phosphorus in a vessel filled with common air, the temperature being sufficiently elevated, that the phosphorus may become luminous; the air then soon acquires the odour of ozone, which is quite different from the smell of phosphorous acid, which is formed in the beginning of the experiment.

intensity,) have any remarkable effect in exciting a peculiar smell when applied to the mucous membrane of the nose. By applying electricity to the Schneiderian membrane, in all cases a more or less painful scratching and tickling is caused, owing to the irritation of the sentient nerves, with which this membrane is richly endowed; sometimes sneezing, as reflex movement, follows the application of electricity to the nose.

Ritter is the only observer who has experimented with a very intense electric current upon his own Schneiderian membrane.* He used a current generated by a voltaic pile of twenty pairs; the inconvenience caused to him by the experiment was frightful. He gives as the result of his researches, that a peculiar smell is excited, not only at the commencement of the current, but also while the circuit remains closed; besides at the cessation of the current, and a certain time after the circuit has been broken. The effects are different according to the direction of the current. If it be inverse, we observe at the commencement of the current, and while the circuit is closed, an acid smell and loss of the capability of sneezing; at the cessation of the inverse current, and a short time after the circuit has been broken, we perceive an ammoniacal smell and disposition to sneezing. If, on the other hand, we employ the direct instead of the inverse current, the contrary is perceived, viz. ammoniacal smell and disposition to sneezing on establishing the circuit, and while the current continues to pass; and an acid

* Beiträge zur nähren Kenntniss des Galvanismus. Weimar, 1805.

taste and loss of the capability of sneezing, on breaking the circuit, and a short time after it has been broken.

3. *Organ of hearing.*

If the drum of the ear is galvanized, sounds are heard by the one subjected to the experiment. The best way to effect this is to fill the external opening of the ear with warm water; a metallic conductor, connected with the negative pole of a battery, or an induction apparatus, is then held in the liquid, and the circuit is closed by placing another moistened conductor on the nape of the neck.

The drum of the ear is equally excitable by the continuous and the induced current. If we make use of the continuous current, sounds are produced not only at the commencement of the current, but also while the circuit remains closed. Volta relates, in a letter to the Right Hon. Sir Joseph Banks,* that when he introduced the poles of a pile of 30 to 40 pairs into the external opening of the ear, he felt a shock to his head, and some moments afterwards he heard a sound, or rather a noise, like scratching and bubbling, or like that of a viscid substance boiling. This noise continued without interruption, and became even more intense until the circuit was broken. But we may produce sounds by means of a much feebler current, such as is produced by a battery of three to four pairs. The effect is always strongest if the negative pole is applied to the ear.

The action of the induced current upon the drum of

* Philosophical Transactions, 1800, p. 423.

the ear presents some differences according to the intensity of the current, and to the greater or less velocity with which the intermittences succeed each other. A single shock from an induction apparatus produces a noise like a scratch; if the shocks succeed each other rapidly, the noises do so likewise, and then resemble the buzzing of a fly on a window, or the blow of a distant trumpet. At the same time a sensation of tickling, and even pain, is perceived, if the current be of high tension.

Ritter has taken much trouble to distinguish the pitch of the tone produced by the galvanic excitation of the drum of the ear. He states that, when both his ears were enclosed in the circuit, at the commencement of the direct current he felt a strong shock, and heard the sound G. This persisted as long as the direct current continued to circulate; if the intensity of the current was augmented, the sound became higher than G. On the contrary, when the inverse current was used, the sound was lower than G, and continued to become lower in proportion as the intensity of the current was increased. Both sound and shock were weak on breaking the circuit, alike when the current was direct or inverse.

I have made a number of experiments with all sorts and directions of currents, and compared the sound produced by the galvanic excitation of the drum of the ear with that given by a tuning fork of the present philharmonic pitch; and I have always found the sound produced by electricity as near as possible to A. I have never observed that by changing the direction of the cur-

rent, or by increasing its intensity, the *pitch* of the sound was changed; the only difference I have perceived was in the *intensity* of the tone. It was stronger if the negative pole was directed to the ear, and the positive to the nape of the neck, than if the position of the poles were reversed. The tone was hardly perceptible if a current of low tension was used, and very loud if it was of high tension; but the pitch invariably remained the same.

By the galvanization of the membrana tympani in living man, two other remarkable phenomena are produced, viz.: a slight and unpleasant metallic taste, and a more or less abundant flow of saliva. The former of these phenomena has been noticed by Duchenne,* and Baierlacher;† the latter has not been signalized until the present time.

The production of this peculiar sensation of taste is due to an excitation of the trunk of the chorda tympani, which, after having emerged from the cavity of the tympanum through the fissura Glaseri, descends toward the lingual nerve, in the sheath of which it enters, and then further proceeds towards the tongue. It is proved by electro-physiology that the chorda tympani essentially contributes to the perception of taste; and clinical experience confirms this physiological induction; as in certain cases of paralysis of the portio dura, there is a loss of taste, together with palsy of the muscles of the face;

* De l'électrisation localisée et de son applicatlon à la physiologie, la pathologie, et la thérapeutique. Paris, 1855, p. 809.

† Die Inductions-Elektricität. Nürnberg, 1857, p. 98.

this loss of taste exists only on the affected side, and usually disappears at the same time with the other symptoms of the paralysis of the portio dura. Several cases of this kind have been recorded by Dr. Gull* and others.

A not less remarkable phenomenon is the flow of saliva produced by the galvanization of the drum of the ear. My attention was directed to this fact in the following way: having often been requested to try the effects of galvanism on patients suffering from what is commonly called nervous deafness, I noticed that the patients during the operation made movements of deglutition; I then experimented on myself with the view of ascertaining the cause of these movements, and found that, if a current of rather high tension was caused to act upon the chorda tympani, the saliva began to flow more or less abundantly. It is evident that this is due to an electric excitation of those fibres of the chorda tympani, which do not proceed towards the tongue with the lingual nerve, but are detached from the principal part of the chorda tympani, and penetrate into the submaxillary ganglion. The saliva, therefore, which is observed to flow when the chorda tympani is being galvanized, is secreted in the submaxillary gland.

We shall see afterwards that direct galvanization of the lingual and auriculo-temporal nerves, as well as of the chorda tympani, and the posterior parotideal branches of the facial nerve in animals, excites an abundant flow of saliva.

* A further report on the value of electricity as a remedial agent, in Guy's Hospital Reports. Vol. viii. Part I. 1852, p. 81.

4. *Organ of taste.*

That a peculiar sensation of taste perceived when the tongue is touched by two heterogeneous metals, has been known long before the discovery of galvanism. M. Sulzer seems to have been the first whose attention was directed to this fact. In a paper which was published by him in the Reports of the Berlin Academy of Sciences, in 1754,* the following remarks occur: "If a piece of lead and a rod of silver are connected with each other, and approached to different parts of the tongue, a sensation of taste is experienced, which resembles that produced by vitriol of iron; while, if we employ either of the metals alone, not the slightest taste is perceived. It is probable that by the connection of the two metals a vibration is produced in the smallest particles, either of the lead or of the silver, or of both of them; and that this vibration, which must necessarily affect the nerves of the tongue, produces the taste described." This is in so far interesting, as it is in all probability the very first observation ever made on the physiological effects of galvanic electricity.

If we apply a single pair of zinc and silver to the tongue, the zinc being directed to the top, and the silver to the back, of the tongue, a very remarkable acid taste is produced under the zinc plate, and a feeble alkaline taste under the silver plate. These sensations are not

* Recherches sur l'origine des sentimens agréables et désagréables; in Histoire de l'Académie des Sciences et Belles Lettres de Berlin. 1754, p. 356.

only perceived at the commencement and at the cessation of the current, but also as long as the circuit is closed. The effect is most distinct when the tongue is at its ordinary temperature, and when the metals are of the same temperature as the tongue. When either the metals, or the tongue, or both, are heated or cooled, as far as can be borne without inconvenience, scarcely any sensation is produced; and whatever has a tendency to blunt the sensibility of the tongue, such as acids, pepper, laudanum, spirits, etc., diminishes the effect of galvanism.

If, instead of a single pair, a pile be used, we observe not only the specific sensation of taste, but also a flash of light, pain in, and convulsions of, the tongue. The interrupted current produces only the latter phenomena, but no peculiar sensation of taste. Frictional electricity, however, has an action on the tongue, which resembles that produced on it by galvanic electricity. Fowler has compared the taste produced by common electric sparks to the taste of vinegar, and that produced by galvanism to the taste of diluted sulphuric acid.

This remarkable affection of the tongue by electricity may be explained in various ways. Thus it may be urged that the sensation of taste is due to a peculiar state of the gustatory nerve produced by electricity, just as a sensation of light is produced by directing the galvanic stimulus to the retina. But the differences in the taste beneath the different poles seem to lead to the conclusion, that the effect is due to an electrolysis of the salts of the saliva, as from muriate of soda, which is dissolved in the saliva,

muriatic acid would be evolved at the zinc pole,—whence the acid taste; and soda at the silver pole,—whence the alkaline taste. It has been objected to this explanation, that a current which is too feeble to bring about a decomposition of the salts of the saliva, will produce a remarkable sensation of taste; besides, we know that frictional electricity produces a marked sensation of taste, although its chemical powers are so feeble that it seems scarcely possible to assume an electrolysis of the salts of the saliva by a few electric sparks. Finally, Volta has observed that an acid taste was perceived under the zinc pole, even when the mucous membrane of the tongue was in contact with an alkaline solution, by which the acid, which might have been formed, immediately would become neutralized, so as to produce no physiological effect whatever.

Professor Schönbein has ventured another explanation.* He supposes that by the galvanic current air becomes decomposed, and that, at the positive pole, the oxygen and nitrogen combine to form nitric acid; which would produce the acid taste. But Schönbein does not explain the cause of the alkaline taste which is perceived under the silver pole, and it seems doubtful if the action of one galvanic pair, or of a few and small electric sparks, is sufficiently powerful to produce a decomposition of air. We are, therefore, at present obliged to content ourselves

* Ueber einige mittelbare physiologische Wirkungen der atmosphärichen Elektricität. Henle und Pfeufer's Zeitschrift. 1851. Heft III. p. 385.

with the following view: that the sensation of taste is probably due to a peculiar state of the gustatory nerves caused by electricity.

IV. *Action of the electric current upon the motor nerves and muscles.*

If a motor nerve of an animal recently killed be subjected to the action of a continuous galvanic current, contractions of all the muscles animated by this nerve are produced, on closing as well as on opening the circuit, whether the current be direct or inverse. Care must be taken, however, that the electrodes connected with the poles of the battery be placed at two points of the nerve which, although they may be near each other, are at a different height, so that the electric current may traverse the nerve in an oblique direction. If the current were to pass transversely through the nerve, one electrode being applied to the right, and the other to the left, side of the nerve, at the same point of its transverse section, no contractions would take place.

It was Luigi Galvani, of Bologna, who first observed, in 1786, that when the nerves and muscles of a frog were connected by means of an arc composed of two different metals, powerful contractions of the muscles took place.* Soon after Galvani's discovery had been made known, Volta found that these contractions also took place, if

* De viribus electricitatis in motu musculari commentarius. Bologna, 1791. This essay was published five years after Galvani had first made his discovery.

the nerves alone were enclosed in the circuit.* In their first experiments, Galvani and Volta noticed only the contraction produced on establishing the circuit; it was another Italian philosopher, Valli, who soon afterwards observed another contraction caused by breaking the circuit.† It has lately been asserted by M. Duméril, that these observations had been made a long time ago by the Dutch philosopher, Swammerdam, who had shown the experiment to the Grand Duke of Tuscany, in 1668.‡ Duméril's assertion has been repeated by Matteucci and Dr. Golding Bird; but a close examination of Swammerdam's experiments shows that the contractions he observed were produced by a mechanical irritation of the nerve, and not by galvanism.

Before we enter more fully into the interesting phenomena brought about by the galvanic excitation of the motor nerves and muscles, it is necessary to state that the contractions produced by the entrance and the cessation of the current do not take place in consequence of the motor nerve simply conducting the electric fluid to the muscles; although the nerve is undoubtedly a conductor of electricity. But the conductibility of the nerves does not at all explain the physiological effect produced by the electric excitation of the nerves. The contraction of the muscles is not at all determined simply by a par-

* Collezione dell' opere del Cavaliere Conte Allesandro Volta. Florence, 1816. Vol. iv. p. 134.

† Reinhold, Geschichte des Galvanismus, etc. 1792. P. 25.

‡ Annales des Sciences Naturelles. 2 série. Zoologie. Paris: 1810. Vol. xiii. p. 65.

ticular fluid being transmitted to them by the nerves. For if a wet thread be tightly applied to a nerve, so that it becomes thin and reduced to its neurilemma, we shall never succeed in exciting contractions in the muscles animated by this nerve, if the electrodes be applied to the nerve above the point where it has been tied; although by such a proceeding the propagation of electricity is not interrupted, the wet thread conducting equally well as the nerve. Another still more remarkable instance is, that a few drops of ether applied to any point of the nerve, will suspend the contractions of the muscles, if the electrodes be placed above or at the point where the ether has been applied; the contractions, however, will re-appear as soon as the effects of ether have passed off. Finally, if we galvanize the nerves of a frog which has previously been poisoned by woorara, not the least contraction will occur in the muscles animated by these nerves; although woorara does in no way affect the electric conductibility of the nerves, which remains perfectly intact; nor the contractile power of the muscles, for the muscles are seen to suffer commotions if an electric current is directly applied to them without the intervention of the nerves; it is only because woorara destroys that peculiar force by which the nerves are enabled to produce the play of the muscles. Hence it results that contractions of the muscles cannot be produced by the galvanic excitation of the motor nerves, unless the nerves be in a state of integrity. The electric current excites the nerve and puts in action its power of producing muscular contractions; it causes

a disturbance in the molecular equilibrium of the nerve, whereby the nerve is enabled to bring about a shortening of the muscular fibres attended by an increase in their diameter

Volta, whose genius unfolded so many phenomena relating to galvanic electricity, thought the contraction produced at the commencement of the current of easy explanation, but could not well understand why a similar contraction should take place on breaking the circuit; he supposed wrongly that this second shock might be due to a sort of counter-current, produced at the moment when the circuit is broken ("causées par une espèce de reflux du fluide électrique."*) Another view was taken by Lehot,† who stated that during the passage of an electric current through a nerve a part of the electricity accumulated in it, and on the interruption of the current discharged itself, traversing the nerve in an opposite direction, and thus giving rise to contraction. Nearly thirty years later Lehot's theory was again taken up by Marianini;‡ but neither Volta, nor Lehot, nor Marianini have been able to furnish any conclusive proofs in support of their opinions, and we are now able to explain the phenomenon described in a satisfactory way without having recourse to hypotheses unsupported by facts.

* On the electricity excited by the mere contact of conducting substances of different kinds. In a letter to the Right Honourable Sir Joseph Banks. Philosoph. Transactions, 1800, p. 421.

† Gilbert's Annalen der Physik, 1801. Vol. ix. p. 188.

‡ Sur la secousse qu' eprouvent les animaux, etc., in Annales de Chimie et de Physique, par Gay-Lussac and Arago. Paris, 1820. Vol. xl. p. 225.

We have seen that during the time that a continuous galvanic current traverses a motor nerve, no visible effect takes place in the muscles, providing the current of the battery is constant. It appears, therefore, very strange that Matteueci, in a paper on the measurement of the nervous force developed by the electric current,* asserted that a constant relation existed between the consumption of zinc in the production of electricity, and the meeha-nical effect produced in the contraction of a frog's leg, the nerve of which is traversed by the current; as it is obvious that we may with the same quantity of zinc in a galvanic circuit obtain *ad libitum* few or an immense number of contractions, in proportion as we make and break the circuit more or less rapidly. Indeed the remarkable physiological effect occurs at the moment when the density of the current suddenly rises from zero to a certain height, as is the case on establishing the circuit; and, on the other hand, when the density of the current descends again from a certain height to zero, as is the case on breaking the circuit. Proceeding from these facts, Du Bois Reymond has arrived at an electro-physiological law for the motor nerves, whieh he has proposed in the following terms:—"The motor nerve is not excited by the absolute amount of the density of the current, but merely by the variations whieh occur in the density of the current, from one instant to the other; and the physiological effect is the greater, the more considerable are the variations of the density of the current; that is, in proportion as they take place more rapidly, or as they

are more considerable in a given space of time."* It is obvious that this affords a striking analogy to the development of induction currents in coils of wires connected with the poles of a battery; as induction currents are only produced on making and breaking the circuit of the battery, but not while the circuit is closed.

By Du Bois Reymond's law it is easy to explain a number of phenomena which have been observed a long time ago. Thus, for producing contractions it is not absolutely necessary that the current traversing a nerve should be closed or opened, as thereby only the maximum of variation is produced. Physiological effects will also be brought about by minor variations in the density of the current; for instance, if the intensity of the current traversing a motor nerve be suddenly increased; or if another current be suddenly brought to bear upon a nerve traversed by a continuous current; or if a portion of the current traversing a nerve be suddenly diverted, as may be done in the following way: the legs of a frog which has been skinned and prepared as usual, are immersed in two separate vessels filled with water, and connected with the poles of the battery; now, while the current is circulating in the nerves, the two vessels are suddenly connected by means of a conducting body, such as an arc of copper or silver wire; by the wire a portion of the current is withdrawn, and simultaneously with it a contraction is produced. It is obvious that variations of this kind are not so considerable, and the physiological effect, therefore,

† Untersuchungen über thieristhe Elektricität. Berlin, 1848. Vol. i. p. 258.

will not be so striking, as that observed on closing or opening the circuit.

It is also easy to understand from Du Bois Reymond's law the action of an induced current upon the nerves and muscles. Induction currents are instantaneous, they consist only of great and sudden variations, which succeed each other more or less rapidly, in consequence of the commencement and the cessation of the current of the battery, and the magnetization and demagnetization of the soft iron. A single induced current will act just as does the opening or closing the circuit of the battery, there will be a contraction brought about by the disturbance of the molecular equilibrium of the nerve; but the muscle will immediately be relaxed again. But when the induction currents succeed each other rapidly, the contractions caused by them will likewise take place in rapid succession, and the muscle will relax less and less the more rapidly the intermittences be given. In a certain rapidity of the intermittences the contraction will appear continuous, as if produced by the will; this apparently continuous contraction, however, consists only of a very rapid succession of single contractions, the intervals between which are too short to be distinguished. The induction apparatus which I usually employ can furnish 120 currents in a second; so that if it be applied to a muscle, 120 single contractions may be produced in a second, and 7200 in a minute. (This circumstance furnishes a clue to understand why the induced current is a more powerful remedy for paralytic affections than the continuous current.)

Although it is especially the *variations* which occur in the density of the current which are of influence in the production of contractions, the *intensity* and the *direction* of the exciting current are also of great importance.

If a feeble continuous current be applied to a nerve, the nerve will retain its excitability very long, and will not be destroyed, as is done by mechanical and chemical stimuli. But if the continuous current be of a certain intensity (if instead of a single battery a pile be applied,) the nerve will be destroyed, both by the calorific and the chemical action of the pile, especially at the point where the negative pole has touched the nerve. The latter circumstance is partially due to the electrolysis of the salt solution contained in the nerve, and the consequent formation of alkali by which the nerve is cauterized; at the same time, hydrogen is developed around the negative pole in consequence of the decomposition of the water. If a nerve to which an intense continuous current has been applied be afterwards subjected again to the action of a feeble continuous current or an induced current, above or at the point where the negative pole has been applied, no physiological effect whatever is produced; but if the same nerve be excited at a point near to the muscle and beneath the negative pole, a contraction of the muscles animated by it will again be produced. It is only the continuous galvanic current which is capable of destroying a nerve by its calorific and chemical action; if the continuous current be constantly interrupted and re-established again by means of a cut-current or rheo-

tome; or if, instead of the continuous current, induction currents are employed, a destruction of the nerve will not be brought about.

The phenomena produced by the electric excitation of motor nerves will also present certain differences according to the *direction* of the current. This was first pointed out by Pfaff.* To observe such differences, however, it is necessary to employ a feeble current, as furnished by a single galvanic pair; if the current of a powerful pile were used in such experiments, no differences would be observable.

These differences may be thus described: when the nerves are in the highest degree of excitability, as is the case immediately after death, and when the nerves have not been subjected to the action of the galvanic current, we are generally not able to distinguish if the contractions produced by the excitation of the nerves be more powerful by the direct or the inverse current, and on closing or on opening the circuit. But if the nerve has lost some of its excitability, as is the case a certain time after death, and when it has been somewhat exhausted by the action of the continuous currrent, a difference is to be noticed in the physiological effect. If a direct or downward current be applied to the nerve, the contraction is produced only at the moment when the circuit is established, but not while the current continues to traverse the nerve, nor at the moment when it ceases to pass; on the other hand, if an inverse or upward current be sent

* Uber thierische Electricität und Reizbarkeit. Leipzig, 1795, p. 74.

through the nerve, there are no contractions at the commencement of the current nor while the circuit remains closed, but only at the moment when the circuit is broken. If we employ in such researches a frog prepared in the manner of Galvani, and immerse the two legs in two vessels filled with water and connected separately with the poles of the battery, contractions will no longer take place in both limbs at the same time, as was the case immediately after the death of the animal; but a contraction will be observed on *making* the circuit in that leg in which the current is direct or downwards, and on *breaking* the circuit in the other leg in which the current is inverse or upwards.* If the period elapsed after the death of the animal be still greater, or when the nerves have been subjected very long to the action of the continuous current, only one contraction will remain, viz. that produced by making the direct circuit; and finally, all contractibility will disappear. These differences in the contractile power of the muscles have been most elaborately investigated by Nobili, of Reggio, who has distinguished five different degrees of the excitability of the muscles, the first of which is, where, by the direct as well as by the inverse current, contractions are produced both at the commencement and at the cessation of the current; the last, where neither by the direct nor by the

* To impress this fact upon the memory, Dr. Todd has proposed the following formula, MD BI—making direct, breaking inverse (Cyclopædia of Anatomy and Physiology; Art. Physiology of the Nervous System. Vol. iii. p. 720, M.)

inverse current contractions are to be perceived, whether the circuit may be opened or broken.*

The following table may serve to illustrate

NOBILI'S LAW OF CONTRACTIONS.

	Direct.		Inverse.	
	Making.	Breaking.	Making.	Breaking.
I	Contraction.	Contraction.	Contraction.	Contraction.
II	Strong contract.	Feeble contract.	. .	Strong contract.
III	Strong contract.	. .	. .	Strong contract.
IV	Contraction.	. .	. .	. .
V	. .	. .	. .	. .

It is very probable that these differences depend upon certain changes brought about in the current proper of the nerves, after the separation of the nerves from the animal body. But it is not to be presumed that Nobili's law is invariable; it has been observed that in some instances just the contrary did happen, viz. a strong contraction on breaking the direct and on making the inverse current. These variations, which, it is true, are of rare occurrence, are probably to be accounted for by certain differences which exist in the nutrition of the nerves and muscles, and by the different way in which these parts have been treated after death. Besides, it will be well to state in regard to the different periods of excitability of the muscles, that we may observe two and even three of these periods in the same nerve at the same time, provided that the nerve be excited at different points of its length. This depends upon the circumstance that the

* Memorie ed Osservazione edite ed inedite del cavaliere Leopoldo Nobili, Florence, 1834, vol. i. p. 135; and Annales de Chimie et de Physique, Mai, 1830, vol. xliv. p. 60.

nerves, when they have been separated from the nervous centres, die in a direction from the centre to the periphery, as was first pointed out by Valli and Ritter: the vital energy will, therefore, remain longest in the terminal branches of the nerve; thus it may happen that we observe contractions both at the commencement and at the cessation of the current, whatever may be the direction of the current, if the terminal branches of the nerve be excited; but if we excite the nerve nearer to the centre, we may observe only two contractions, viz. on making the direct and on breaking the inverse; while if the nerve be acted upon close to the spinal cord, a contraction is caused only on making the direct current. From this we may infer that the manifold differences noticed in the contractions have not that important physiological bearing which had been attributed to them by previous observers. It is quite true that there are different periods of excitability in the nerves after they have been separated from the animal body. But these do never occur in the living nerves, so long as they are connected with the nervous centres; they are merely the result of the fatigue of the nerves necessarily brought about a certain time after their separation from the animal body; a fatigue which will be accelerated if the nerves have been repeatedly subjected to the action of the galvanic current.

Before we leave this subject, it is necessary to mention the experiments which have been made by Messrs. Longet and Matteucci,* in order to determine if different

* Annales de Chimie et de Physique. 3 série. Paris, 1844. Vol. xii. p. 574.

physiological effects would be brought about by the galvanization of the motor and of the mixed nerves; that is, the pure motor nerves, before they have received sensitive fibres from the posterior roots, or the motor nerves after sensitive fibres have been associated with them.

They say that if the anterior roots were galvanized, contractions were only produced on making the inverse current and on breaking the direct, while the contrary would be observed if the mixed nerves were subjected to the action of the current; viz. a contraction on making the direct and breaking the inverse current. Hence they concluded that we might be able to tell the nature of a nerve, whether mixed or purely motor, by merely applying to them a continuous current, and noticing the physiological effect produced by it. These results have unfortunately, not been confirmed by the recent and more exact researches of Claude Bernard and Rousseau,* so that the assertions of Messrs. Longet and Matteucci deserve a place only in the history of the physiological science.

Until now we have only considered the phenomena produced by the variations of the electric current in the nerves; we now proceed to take up the important question, if there be any physiological effect produced during the time that a closed continuous current traverses a nerve?

The first who directed his attention to this subject was

* Leçons sur la Physiologie et la Pathologie du Système Nerveux, par M. Claude Bernard. Paris, 1858. Vol. i. p. 167.

Ritter,* who observed that if a frog's leg be traversed for a certain time, say half an hour, by a direct continuous current, it will no longer exhibit any contractions, if the current be interrupted and afterwards established and broken again; but that it will suffer a commotion if an inverse current be applied to the nerve: this commotion is feeble on making the circuit, and strong on breaking it. If now an inverse current be made to act upon a leg, its excitability will be increased. Hence Ritter concluded that the direct current exercises a paralyzing action on the nerve, while the inverse current would augment its irritability.

Three years afterwards Volta made some experiments to determine the effect of the closed circuit of the pile upon the motor nerves.† While Ritter had operated with a single galvanic pair, Volta employed the pile, that is, a much stronger current, and therefore obtained different results, which may be described as follows: Both the direct and inverse current will exercise a paralyzing action when they have traversed the nerve for a certain time. When the nerve has been subjected to the action of a direct current, the frog's limb will no more respond to the excitation of the same; but it will be convulsed anew if an inverse current be substituted to the direct, and *vice versa*. These processes may be repeated several times, and we may thus annihilate and revive *ad libitum* the readiness of the muscles to respond to the galvanic

* Beweis dass ein selbstständiger Galvanismus, etc. Weimar, 1798, p. 119.

† Collezione dell' opere, etc. Vol. ii. p. 219, note (a.)

current. The succession of phenomena just described has been designated by the name of *voltaic alternatives;* but to Ritter the merit is due of having first proved that the closed continuous current has a distinct action upon the motor nerve.

In 1834, Volta's researches upon the action of the closed circuit were repeated by Marianini,* who operated with a pile consisting of sixty pairs of plates, and confirmed Volta's results. Nobili † tried to explain these phenomena in the following way: He assumed three different states in the nerve—*a.* the natural state; *b.* the state of direct alteration, brought about by a prolonged action of a direct continuous current upon a nerve; and *c.* the state of inverse alteration produced by the passage of the inverse current. In order that there should be a commotion in the muscles, there must be a sudden transition in the nerve from one state to the other; and by the prolonged action of a continuous current, whatever may be its direction, the nerve is rendered incapable of transmitting the action of a current moving in the same direction; it only gains back this property if it be allowed to rest for a certain time, or if it be acted upon by a current guided in a contrary direction. But although in general the frog may contract anew, yet its excitability will be found to be diminished, and by repeated applications the excitability of the nerve will at last be entirely destroyed.

* Annales de Chimie et de Physique. Vol. lvi. p. 387. Paris, 1834.

† Ibid. Vol. xliv. p. 60.

Thus it appears that the excitability of the nerve is diminished by a prolonged action of a continuous current of a certain intensity upon the nerve. We may, therefore, ask: is a continuous current capable of paralyzing the action of any stimulus applied to the nerve, or of any irritated state of a nerve produced by any means whatever; and is it indifferent in what direction the current is made to pass through the nerve in order to produce the said paralyzing action?

That a continuous current may, under certain circumstances, quiet an irritated state of a nerve, had already been observed by Nobili,* who remarked now and then in the course of his experiments, that prepared frogs became subjected to violent tetanus without any apparent cause; and that these frogs became quiet if a continuous current was sent through their limbs in a certain direction, while the tetanus remained undisturbed if the current moved in the contrary direction. (Nobili does not state in which direction.) Matteucci † afterwards observed that when frogs, tetanized by strychnia, were subjected to the action of a continuous galvanic current, the tetanus disappeared very soon, and did not come back; the frogs died from the effects of the strychnia, but without the convulsions which are otherwise the consequence of strychnia poisoning. As to the direction of the current, he stated that tetanus would cease by the passage of an inverse current, while it would be increased

* Memoire, etc., p. 91.

† Comptes Rendus, etc., Mai, 1838. Vol. vi. p. 680.

by the direct current. Together with M. Farina, he tested even the therapeutical effect of the continuous current in a patient who suffered from traumatic tetanus in consequence of having been shot through the leg. He caused a current of thirty to forty pairs of plates to pass along the spinal marrow in the direction from the sacrum to the nape of the neck, and introduced the patient gradually into the circuit in order to avoid muscular commotions. The patient opened his mouth, the circulation and transpiration were re-established, and the patient appeared generally comforted, but died nevertheless afterwards, the irritation having been kept up by foreign bodies in the wounded limb.

Another instance has been mentioned by Du Bois-Reymond,* who remarked that in a tetanized limb of a frog the gastrocnemian muscle became quiet as soon as the sciatic nerve was laid upon the tendon of the muscle; that is, if the *inverse* current proper of the muscle was made to pass through the nerve; but that the tetanus continued unchanged, when the nerve touched the flesh of the muscle, that is, when the *direct* current proper of the muscle traversed the nerve.

The most important researches, however, bearing upon this question, have recently been undertaken by Professor Eckhard, of Giessen,† who was led to the conclusion that if a constant continuous current of a certain intensity and direction be made to pass through a nerve, the excitabili-

* Untersuchungen, etc., vol. i. p. 384.

† Beiträge, etc., p. 25.

ty of this nerve will be so much diminished that any mechanical, chemical or electrical stimulus, which would otherwise bring about a contraction of the muscle, will no longer be able to induce such contractions, so long as the galvanic current continues to traverse the nerve; but that as soon as the circuit has been opened again, contractions will be brought about if the nerve be excited anyhow.

In order to ascertain the difference in the action of a direct and of an inverse current, Professor Eckhard has made three series of experiments, with two pairs of Daniell's battery.

I. He placed the positive electrode at a certain point of the nerve, and the negative lower down; he then tetanized the muscles by applying some salt water to the nerve, at a point *between* the two electrodes; as soon as the electrodes had been connected with the poles of the battery, that is, a direct continuous current traversed the irritated nerve, the tetanus disappeared; when the circuit was opened again, the tetanic convulsions set in as before. The paralyzing effect was more striking if, instead of the direct, the inverse current traversed the nerve; the inverse current of the same intensity being able to counterbalance a stronger stimulus, which was only slightly diminished by the direct current.

II. The continuous current was made to pass through a motor nerve, as above, and afterwards a stimulus applied, not between, but *above* the electrodes. The result was the same as in I.; both the direct and the in-

verse current exercised a paralyzing action, but that of the inverse was more remarkable than that of the direct. If, instead of a mechanical or chemical stimulus, an induced current was used to excite the nerve, the paralyzing effect was strongest, if both the continuous and the induced current moved upwards.

III. An inverse continuous current was sent through a nerve, and the stimulus no more applied between or above, but *beneath* the electrodes; the paralyzing effect was again observed, whether salt water or the induced current were used as excitants. Then a direct continuous current was made to pass through the nerve, and the curious fact observed that in this instance the continuous current did not only exercise no paralyzing effect at all, but that, on the contrary, the excitability of the nerve was increased by its passage. Tetanus, brought about by the application of salt water to a nerve, became much stronger as soon as the electrodes of a direct continuous current were placed above the excited point. It was even observed that if a nerve had been immersed in salt water, and the tetanus had not yet made its appearance, it came on immediately after the circuit had been established in the way described. If two shocks of an induction apparatus were applied to the nerve, one before the commencement of the continuous current, and another one after the circuit had been established, the contraction produced by the second shock was stronger than that by the first. Hence it results that an inverse continuous current of a certain intensity, when traversing a motor

nerve, will enfeeble its excitability altogether, whatever may be the point of the nerve to which the stimulus may have been applied, and whatever may be the nature of the stimulus itself; while a direct continuous current, when passing through a motor nerve, will diminish its excitability only at those points to which the electrodes themselves are applied, and in all points beyond the positive pole; but that it tends to increase the excitability of the nerve on all those points which are beneath the negative electrode. Thus, if the last case did not form an exception, the continuous current might be fairly termed the paralyzing current. The following table may serve to illustrate the action of the continuous current:—

	I.	II.	III.	IV.	V.	VI.
	☝	☝	☝	☟	☝	☟
	—	—	—	Stimulus.	+	+
	Stimulus.	Stimulus.	+	+	Stimulus.	—
	+	+	Stimulus.	—	—	Stimulus
Effect	Paralyzing	Paralyzing	Paralyzing	Paralyzing	Paralyzing	Exciting

In this table the tubes I.—VI. represent nerves; ☝ and ☟ the upward and downward direction of the current, stimulus, —, and +, those points of the nerves where the stimulus and the positive and negative electrodes have been applied. The effect of the continuous current will be paralyzing in I.—V., but exciting in VI.

A few other instances of the paralyzing action of the continuous current may be given. It is well known that the vagi do not form the motor system of the heart, but that they regulate the movements of the heart which are only caused by sympathetic fibres; therefore, if the vagi

be excited, the pulsations of the heart are retarded, and finally brought to a stand-still. This is the case if an induced current be applied to the vagi. Very quick pulsations of the heart indicate a paralytic state of the vagi, or a state approaching paralysis; thus the pulsations of the heart become innumerable, if a section of the vagi has been made. Nearly the same is observed if the vagi be subjected to the action of a continuous current; namely, a great acceleration of the pulsations of the heart.

Similar phenomena are observed in the lymph-hearts of frogs and other reptiles, the pulsations of which depend upon the nerves which arise from the spinal cord, and thence go to the lymph-hearts. If a section of these nerves have been made, the movements of the lymph-hearts disappear. They may re-appear some time afterwards, but then they will present quite another type of contractions, since only some parts of the lymph-hearts will contract, or if, what is of rare occurrence, the whole heart be seen to contract, the rhythm is wanting which had been apparent before the section of the nerves had been made. On the other hand, a single shock from an induction apparatus produces systole of the lymph-hearts; and if a succession of induced currents be applied to them, the maximum of contraction is produced, viz.: a stand-still of the lymph-hearts during systole, while, if a continuous current be made to pass through the nerves, a paralytic stand-still of the lymph-hearts during diastole will be brought about.

The galvanic excitation of the motor nerves, when they are still in their normal connexion with the nervous centres, does not yield exactly the same results as we obtain by experimenting upon nerves which have been separated from the living animal, even if this should have been done only a very short time ago. Thus it was first pointed out by Bernard, that if a nerve was galvanized while still connected with the spinal cord of the living animal,—that is to say, in its normal physiological condition,—a contraction was produced only on establishing the circuit, whatever might be the direction of the current. But if the nerve was fatigued by any cause, as, for instance, by the prolonged and energetical action of a galvanic current, or by the action of heat during summer, or if the nerve was cut or tied above the point which was touched by the electrodes, two contractions were produced, one at the commencement, and another at the cessation of the current; these two contractions are, therefore, an index of a fatigued state of the nerve. If the fatigue becomes greater, contractions are only produced on making the direct and breaking the inverse current; finally, we obtain only a single contraction on making the direct current. These four different periods succeed each other much more rapidly in summer than in winter, as cold weather is favourable to the continuance of the excitability of the nerve. Similar phenomena may be observed in man. It was pointed out by Drs. Todd, Fick, and Orelli, that the contraction produced at the commencement of the continuous current is always the strongest,

whatever may be the direction of the current, and that at the cessation of the current there is either a very feeble contraction, or no contraction at all. It is well to add, that the action of induction currents is the same on living nerves connected with the nervous centres, and on nerves which have been separated from the brain or spinal cord.

As the experiments of Professor Eckhard on the action of the closed continuous current upon the motor nerves have only been made on frogs' limbs separated from the body, I have been anxious to inquire if the same results would be obtained on a nerve still connected with the nervous centres. In order to ascertain this, the crural nerve of a living rabbit was laid bare, and the continuous current of three large plates of Daniell's battery applied to it. The contraction was obtained, as in Bernard's experiment, only on closing the circuit, whatever was the direction of the current. After the contraction produced by making the circuit had passed off, I applied a stimulus to the nerve which was traversed by the continuous current; viz.: an induced current which had been made feebler by the interposition of a layer of water into the circuit. The result of this experiment was that the continuous current always proved paralyzing, whether the stimulus was applied between, above, or below the electrodes, and whether the current was direct or inverse. The shock from the induction apparatus produced a most marked contraction, when the nerve was not traversed by the continuous current; but as soon as the circuit was closed, the induced current failed to bring about a contraction.

The action of the closed continuous current upon the motor nerves is, however, widely different according to the more or less considerable intensity of the current. We have been lately favoured with some interesting physiological researches on the action of a very powerful continuous current upon the motor nerves, by Dr. Remak,* whose experiments would have attracted more notice than they have done, if they had not been propounded as the foundation of a most extravagant therapeutical system, which could not possibly command the attention of the Profession.

The following is the substance of Dr. Remak's experiments:—A current produced by thirty plates of Daniell's battery was sent through the trunks of nerves, and some time afterwards contractions were observed in the antagonistic muscles. Thus, for instance, when he acted upon his own median nerve, Dr. Remak felt a sort of tingling in all the parts animated by branches of the median nerve, and observed a contraction, which gradually increased, in the antagonistic muscles, viz. in the extensors of the wrist and of the fingers. The hand was elevated to an angle of about 45°, and the fingers were extended. This contraction was kept up as long as the current of the battery continued to circulate in the median nerve, but the hand immediately dropped on breaking the circuit. Dr. Remak states besides that he was able to resist the involuntary extension of the hand while the circuit

* Galvanotherapie der Nerven—und Muskelkrankheiten. Berlin, 1858, p. 49, *seqq*.

was closed, as he preserved the full force of volition over the muscles animated by the median nerve, but as soon as he ceasèd to resist, the extension of the wrist and the fingers was again produced. He observed the same if he sent a continuous current through the trunk of the radial nerve, by placing one electrode to the point between biceps and triceps, where the radial nerve may be reached, and the other electrode on the back of the fore-arm, where the interosseous nerve is superficial. He then perceived tonic contractions of the muscles animated by the median and ulnar nerves, that is to say, flexion of the hand and the fingers. These contractions are termed by him, galvano-tonic contractions; to produce them, a current of enormous intensity is always necessary. Usually this current is excessively painful to bear, and in some instances the current may even excite horrible pain without producing any galvano-tonic contractions at all, while in other instances less pain may be experienced, and the contraction will be well marked. If a certain length of the nervous trunk be traversed by the current, the contractions will be more easily produced than if only a small part of the nerve is acted upon. In some cases it is sufficient to employ twenty to thirty plates of Daniell's battery; in other instances, however, fifty are necessary. Besides, in the same individual the phenomena may be different on different days; viz. at first, contractions of the muscles animated by branches of the nerve which is traversed by the current, and at another time contraction of the antagonistic muscles; sometimes even a struggle may be observed between the different

groups of muscles, so that at first a flexion may be produced, and some time afterwards extension, while the current continues to traverse the same nerve! In Dr. Remak's opinion these contractions are not produced by the direct excitation of the nerves, but they are reflex movements, produced by the excitation of the nervous centres.

So much for the remarkable phenomena brought about by the electric excitation of the motor nerves: we now proceed to consider the question whether or not the electric current has any direct and immediate action upon the muscular fibre, without the intervention of nervous filaments. If it should be proved that there is such a direct action upon the muscles, a question would be decided which has occupied the attention of the greatest physiologists for more than a century, and on which, at the present moment, the first physiologists of all countries still disagree.* I mean the question as to the existence or not of Hallerian irritability. Is there a *vis musculosa insita*, a property inherent in the muscular fibre capable of being excited to action independently of the immediate instrumentality of the nerves, or are the nerves the only excitors of muscular motion; and is it always necessary in order to bring about muscular contraction, that the motor nerve of the muscle should be previously irritated?

* The non-existence of Hallerian irritability has been chiefly maintained by Baron Humboldt, the late Dr. Marshall Hall, J. Muller, Sticker, Weber, Eckhard, Remak, Friedberg, and others; in opposition to Volta, Marianini, Matteucci, Mr. Bowman, Longet, Claude Bernard, Kölliker, and others.

It is obvious that it would not be difficult to answer the question satisfactorily, if it were as easy to prepare muscular fibres without nervous matter, as it is to prepare nerves without muscular substance. But even if the greatest care be taken to remove every nervous fibril from the muscular tissue, we generally discover, by means of the microscope, small nervous filaments still adhering to the muscular fasciculi. The question may therefore be decided in two ways: on the one hand, if muscular fibres be placed under the microscope, and it be decided that they really are pure and simple muscular, without any trace of nervous fibrils, the irritability proper of the muscles would then be proved if these fibres were seen to contract on a stimulus being applied to them. On the other hand, the question might be decided if it were possible to find a drug which would kill the motor nerves and leave the muscles intact, so that a complete separation of the two tissues could be easily effected. It is obvious that the latter way would eventually be the most secure, as a very small nervous filament might possibly escape the notice even of an experienced microscopist working with a good instrument. But if it should happen that both sorts of inquiry yield the same result, we shall be justified in positively answering the question, and we may then be allowed to declare further discussions upon the subject waste of time. Glisson seems to have been the first who used the word irritability. He says:* "Motiva fibrarum facultas, nisi irritabilis foret,

* Francisci Glissonii tractatus de Ventriculo et Intestinis. Lugdun, Batavor, 1691, p. 168.

vel perpetuo quiesceret vel perpetuo idem ageret. Actionum igitur earum varietates et differentiæ earundem irritabilitatem clare demonstrant." But Glisson ascribed an irritability proper to all the tissues, even to the bones and fluids of the human body, while Haller was the first to point it out as a property inherent to the muscular fibre.* He termed irritable part of the human body (muscular fibre) such as is shortened if touched by any foreign body; on the contrary, he called sensitive fibre (nervous fibril) that which, if touched, transmits to the mind the impression of contact, and the irritation of which in animals occasions evident signs of pain and discomfort. According to Haller, sensibility and irritability are properties totally independent of each other. Most tissues are sensitive, and this property is possessed by them in a direct proportion to the quantity of nervous fibrils they contain; a part, the nerves of which have been cut or tied, has lost its sensibility; parts which are devoid of nervous fibrils, as the dura-mater, the cornea, the tendons, are not sensitive. But the nerves do not possess the slightest amount of irritability, since they are never put in motion themselves, whatever may be the stimulus which is applied to them. Sensibility is a property which ceases with life. Irritability, on the contrary, is to be observed a certain time after life has become extinct, or after the nerves of a part have been cut; it is by no means so generally diffused in the system as sensibility, as it is possessed merely by the muscles,

* Elementa Physiologiæ. Vol. iv. lib. xi. Lausannæ, 1762.

the intestines, chylifera, and arteries. These parts are not sensitive, or, if they are, it is by no means a property inherent to their structure, but merely a consequence of the few nervous fibrils which are mixed up with them. If motion be brought about by the instrumentality of the nerves, it is only by their conducting the order of volition to the muscles, and by strengthening their inherent force. Thus Haller was the first to make the distinction between the *functions* of motion and sensation; he is, in this respect, the precursor of Sir Charles Bell, who pointed out that there are also different *organs* for motion and sensation, viz. the motor and sentient nerves.

Haller supported his opinion especially by reference to the disproportion that exists between the bulk of the nerves and the contractile power of those organs in which they are ramificated. Thus the heart, which has the most remarkable contractile power of all the muscles of the animal body, has very few and small nerves only, etc. Haller's chief opponent, at the time, was a distinguished German physician, Dr. Unzer,* who proved that there are nerves in all muscular organs, and maintained that the nerves were the only excitors of muscular motion; when motion occurs in muscles, the nerves of which have been cut or tied, the motion is, according to Unzer, solely due to the fine nervous filaments, which always remain mixed up with the muscles. Unzer's view, however, was contested by Felice Fontana,† who supported his opinion

* Erste Gründe einer Physiologie. Leipzig, 1771.

† Ricerche Philosophiche sopra a Fisica Animale, 1775. Vol. i. p. 123.

by an important experiment. He cut the crural nerves of frogs, and observed that, after a certain time, the muscles of the thigh still contracted, when a stimulus was applied directly to the muscular substance; but that the muscles remained perfectly quiescent if the nervous trunks were irritated.

After the discovery of galvanism the question was again taken up with much interest. Galvani, Volta, and Valli maintained that muscular contractions were most decidedly caused by the "metallic stimulus," if the muscles alone were touched by the galvanic pair; but others, like Fowler, thought that we should never arrive at a solution of this question, since it would always be impossible to satisfy ourselves whether nerves had not been present in a muscle contracted by the galvanic stimulus.*

The same view was taken by Baron Humboldt, who maintained that, if a piece of muscular flesh was so prepared that no nervous fibril was visible in it (as may best be done, he says, in the upper part of a frog's thigh, or in the fins of a fish,) there was no contraction caused by the galvanic stimulus; and if there was a contraction, it was easy to distinguish, by means of a magnifying glass, traces of nervous filaments which, in spite of careful dissection, had been left in the muscular substance. He therefore was led to the conclusion that irritability is a

* Experiments and Observations relative to the Influence lately discovered by M. Galvani, and commonly called Animal Electricity. Edinburgh, 1793, p. 64.

property of the compound structure, the nerves receiving the stimulus, and the muscles undergoing contraction.*

Fifty years later, the same opinion was pronounced by the late Dr. Marshall Hall, who thought the question, whether the property of irritability belonged to the pure and isolated muscular fibre, or to the muscular fibre combined with the nerves, could not be determined by distinct experiment, and that irritability belonged, in all probability, to the compound structure.†

In 1834, Fontana's experiment, to which I have alluded above, was repeated by Dr. Sticker under the superintendence of J. Muller of Berlin.‡ Sticker found that some weeks after the section of the nerves had been made, neither the nerves nor the muscles responded to the galvanic stimulus. But Longet rightly objected to this, that Sticker had allowed too much time to elapse before he compared, the excitability of nerves and muscles. Another objection which, in my opinion, should be made to Sticker, is that in his researches he used only a galvanic pair to excite the muscles, and that perhaps he might have succeeded in obtaining muscular contractions, if he had used a powerful battery instead.

The experiments of Fontana and Sticker were repeated by Longet,§ and he was anxious to examine the nerve

* Versuche uber die gereizte Muskel und Nervenfaser. Posen und Berlin, 1797. Vol. i., p. 105.

† Article, Irritability, in Cyclopædia of Anatomy and Physiology, 1847. Vol. iii., p. 29.

‡ Ueber die Veränderungen der Kräfte durchschnittener Neven. Müller's Archiv., etc., 1834, p. 202.

§ De l'irritabilité musculaire. Archives Générales de Médecine. 3 série. Paris, 1842, vol. xiii. p. 81.

during the first few days after the operation. He found that a motor nerve, which has been separated from the nervous centres, will lose every trace of excitability on the fourth day after it has been cut; any mechanical, chemical, or electrical stimuli, will then fail to produce muscular contractions, if they be applied to the free extremity, or the branches of the nerve; on the contrary, a muscle, the motor nerve of which has lost its excitability, will visibly vibrate under the influence of a stimulus, even twelve weeks after the section of the nerve has been made. From this Longet inferred that the motor nerves are not the only excitors of muscular motion; that muscular irritability is independent of the motor nerves; and depends essentially upon the supply of arterial blood, a condition necessary, not to impart or communicate to the muscles the property in question, but only to maintain in the muscular tissue the nutrition which keeps up the vital properties of all the tissues of the animal body.

Dr. John Reid was led to the same conclusion as Longet.* In order to render the success of his experiments more secure, he thought it well to exercise the muscles by a proper stimulus. He cut the spinal nerves in the lower parts of the spinal canal in four frogs, so that both hinder extremities were insulated from their nervous connections with the spinal cord. He then daily exercised the muscles of one of the paralyzed limbs by a weak galvanic current, while the muscles of the other limb were allowed to remain quiescent. This was continued for

* Edinburgh Monthly Journal of Medical Science. May, 1842, p. 327.

two months, and at the end of that time the muscles of the galvanized limb retained their original size and firmness, and contracted vigorously, while those of the quiescent limb had shrunk to at least one-half of their former bulk, and presented a marked contrast with those of the galvanized limb. But even at the end of two months the muscles of the quiescent limb had not lost their contractility.

Stannius repeated these experiments, and found that the muscles still retained their irritability six months after the nerves had been cut, while the nerves had lost their excitability much earlier. The muscles, which did not contract on irritation of the nerves, responded readily to the electric current applied directly to their tissue. But Stannius himself suggested that this is no conclusive proof for the existence of Hallerian irritability, since the nerves die in a direction from the centre to the periphery (law of Valli and Ritter,) and that, therefore, while the trunks of the nerves had lost their excitability, still the fine nervous fibrils contained in the muscular tissue might have retained their integrity.*

Marianini concluded from his experiments, that the muscles may be directly acted upon by the electric current without the intervention of the nerves. He says that, when a continuous current acts upon the muscles alone, contractions take place only at the moment the circuit is closed; and he distinguished two sorts of con-

* Untersuchungen über Muskel-Reizbarkeit. Müller's Archiv., 1847, p. 443.

tractions; viz.: *idiopathic* contractions, such as are produced by the direct excitation of the muscles; and *sympathetic* contractions, such as follow the application of the electric current to the motor nerves. But Marianini did not furnish any proofs in support of his opinion.

Matteucci also adopted the view of an irritability proper of the muscles, which he thought was proved by his experiments on the different conductibility of the nerves and muscles. He says that, as muscles conduct electricity better than nerves, no portion of the current will ever traverse the nerves which are mixed up with the muscles, if an electric current is caused to act upon a muscle. He took a muscle of the leg of a rabbit which had been dead a sufficient time for every trace of muscular irritability to have disappeared. He then made an incision in the muscle, and introduced into it the nerve of a very sensitive galvanoscopic frog. He afterwards caused the current of a powerful pile to pass through the substance of the muscle, by applying the electrodes to different points of the muscles; and although a strong current then traversed the muscle in every direction, the galvanoscopic frog did not undergo a contraction, in spite of its nerve being enclosed in the muscle, and forming almost an integral part of it. Care must be taken to employ a muscle which has lost all irritability, lest the frog might suffer contractions which are known as induced contractions. Matteucci's reasoning is no doubt ingenious; but I cannot admit its being conclusive, as the conductibility of a muscle which has lost every trace of excita-

bility is not the same as that of a living muscle, and the conductibility of fine nervous filaments must necessarily differ from that of the trunks of nerves, which offer much more resistance to the passage of the current.

Thus, after manifold and careful researches, the question still remained *in suspenso*, since the supporters of Hallerian irritability had never attempted to prove a contraction of muscular fibres which had been entirely isolated from all connexion with nervous fibrils. The first step in this direction was taken by Mr. Bowman,* who adduced the evidence of direct microscopical observations made on living fragments of the elementary fibres of voluntary muscle, which he had entirely insulated from every extraneous substance, whether nerve or vessel. He observed that if by design or accident a particle of foreign matter was included in the field, so as to touch the side of the fibre at a single point, the fibre exhibited a contraction limited to the point touched, and not involving the whole muscular substance. Hence he concluded that the muscles possessed an irritability proper, capable of being brought into action by a stimulus topically applied. It is obvious that this observation of Mr. Bowman is of paramount importance, and that it greatly contributes to decide the question which we are now considering.

Another way by which it is possible to arrive at a satisfactory conclusion was first pointed out by Harless.† He supposed sulphuric ether to be a substance which would paralyze the nerves by dissolving the fat contained in

* Article Muscular Motion, in Cyclopædia of Anatomy and Physiology, vol. iii., p. 519.

† Müller's Archiv., 1847, p. 228.

them, but would leave the muscular tissue totally intact. To prove this he made the following experiments:—He produced anæsthesia in rabbits; laid bare the brain and the spinal cord, and applied to them the electrodes of an induction apparatus. The muscles remained tranquil, but they contracted powerfully as soon as the electric current was directly applied to them. Similar experiments, however, which were undertaken by Stannius, did not yield the same results, and it remained even doubtful if the terminal branches of the nerves had been really paralyzed by ether.*

Such was the state of the question when Claude Bernard first undertook his experimental researches on the physiological action of the woorara poison.† He took two prepared frogs, and poisoned one of them by inserting under its skin a small piece of woorara. When, at the end of five or six minutes, the frog had ceased to show signs of life, the poison was withdrawn. A galvanic current was then caused to traverse a portion of the lumbar nerve of each of the frogs successively. The muscles of the frog which had *not* been poisoned were immediately seen to suffer a powerful contraction, but not the slightest twitching occurred in the other frog which had been poisoned. On the contrary, when the poles of the pile were directly applied to the *muscles*, both frogs suffered commotions, and it even appeared that the poisoned frog preserved the property of suffering contractions for a longer time than the one which had not been poisoned.

* Müller's Archiv., 1847, p. 413.

† Comptes Rendus. 1850. Vol. xxxi. p. 533.

Thus the existence of an irritability proper of the muscles seemed to be proved; but the old objection was again raised by Eckhard,* that the paralysis of the last ramifications of the nerves had not been proved, and Eckhard concluded from his own experiments on the influence of a closed continuous current upon the excitability of the motor nerves, which I have related above, that the muscles are quite devoid of an irritability proper. He maintained that, if there was an irritability proper, a continuous current which paralyzes a motor nerve would not be able to prevent the contraction of a muscle animated by this nerve, if a stimulus were applied to the muscular substance. But when he applied a stimulus to a muscle, the nerve of which was being paralyzed by a continuous current, he perceived that the contraction was diminished, or that there was no contraction at all. Hence he concluded that the only excitors of muscular motion are the nerves.

But it is obvious that Eckhard's reasoning is not conclusive. In fact, if an electric current produces muscular contraction, it is by the excitation of both the muscles and the nervous fibrils mixed up with the muscles; and if by a continuous current the nervous fibrils are paralyzed, one element causing the contraction will be lost, and, therefore, of course, the contraction will be diminished. Besides, Bernard has recently completely refuted the fundamental objection against Hallerian irritability, which has been raised over and over again since the

* Beiträge, etc., p. 47.

time of Unzer. He observed that the motor nerves lose their excitability from the centre to the periphery (law of Valli and Ritter,) only in case they have been previously separated from the nervous centres.* Thus when the sciatic nerve has been cut off from its connexion with the spinal cord, galvanization of the trunk of the nerve will after a certain time, no longer cause contractions of the muscles; but if we galvanize the branches of the nerve nearer to the periphery, contractions will still be brought about. On the other hand, if the nerve be still kept in its normal physiological connexion with the cord, different phenomena are observed; the nerve, under these circumstances, loses its properties in the inverse ratio, namely, from the periphery to the centre. If the crural nerve of a frog be laid bare, and no more contractions are excited by galvanization of the nerve near the muscles, contractions are still produced if it be galvanized near the cord; and if the whole nervous trunk has lost its excitability, a contraction will even then be brought about by galvanization of the anterior roots of the nerves. It is in this way that the nerves lose their excitability if animals die from hemorrhage or from woorara. It is easy to demonstrate these different modes of death of the nerves on one and the same animal. If the lumbar nerves of the right side of a frog are cut, and the animal be afterwards poisoned by woorara, we observe that the nerves lose their excitability in the direction from the centre to the periphery on the right side, where there is

* Leçons sur la Physiologie, etc. Paris, 1858. Vol. i. p. 193.

no longer any connexion between the nerves and the spinal cord; and that they die in the direction from the periphery to the centre on the left side, where such connexion is still kept up. Therefore, the terminal branches are the first, and not the last, which are destroyed by woorara: and as, in spite of the destruction of the properties of these nervous fibrils, the muscles readily respond to the galvanic stimulus, the existence of Hallerian irritability is clearly proved.

Bernard's researches have been confirmed by a series of experiments undertaken by Kölliker with woorara and coniine: he found the action of coniine nearly equal to that of woorara.* I have myself been able to experiment with woorara, a quantity of which has been kindly given me by my friend, Dr. Stamm, on his return from the Brazils, and I can therefore bear testimony to the accuracy of Bernard's and Kölliker's statements. The following experiment shows best that it is only the motor nerves which are killed by the poison: the crural artery and veins are closely tied up on one side, so that the circulation of the blood in the limb is stopped. The animal is then poisoned by inserting a small quantity of woorara under the skin. If galvanization of the motor nerves be practised a short time afterwards, it becomes evident that all the nerves have lost their integrity, with the exception only of the crural nerve, of that side where the vessels have been tied: this nerve, when galvanized, sets the muscles in play. But if the electric stimulus be

* Physiologische Untersuchungen, etc. Virchow's Archiv. vol. x. 1856.

directed to the muscular substance itself, contractions may be obtained in all the muscles; and the contractile power of those muscles, the nerves of which have been poisoned, will last even longer than in those which have not been, in consequence of the stoppage of the circulation of the blood in the latter.*

Finally, I may mention some microscopic observations of Dr. Wundt, which are likewise in favour of an irritability proper of the muscles. He saw that when the circuit of a galvanic battery was closed in the muscular tissue, the fibres were shortened, and that, after the contraction, produced by the commencement of the current, had passed off, the fibres did not immediately regain their previous length, but remained somewhat shorter than

* I have experienced myself a slight degree of poisoning by woorara. In spite of the precaution I used in handling the drug, on one occasion a very small particle of it came into my blood, having probably been carried into the mucous membrane of the nose by the respiratory movements. The symptoms then observed were the following:—I felt nearly paralyzed, had vertigo, cold sweat on the forehead, and a pulse of 140 to 160. The abnormal sensations soon went off, but the pulse remained at the rate of 128 for nearly a quarter of an hour, when it began slowly and steadily to subside to 72 per minute. I should not mention the occurrence if it were not for the curious circumstance, that although consciousness was not impaired, I had. for two minutes perhaps, lost the knowledge of the English language, in which I had just conversed with a friend of mine who happened to be present at the time; and I was obliged to entreat him to speak German to me. I find a similar circumstance mentioned in Sir Henry Holland's Chapters on Mental Physiology, p. 160, where he relates that having descended on the same day two very deep mines in the Hartz mountains, and having remained some hours under-ground in each, every German word and phrase deserted his recollection, and it was only after he had taken food and wine and been some time at rest, that he regained them again.

they had been before for several minutes. If the circuit was then opened again, there was a difference in proportion as a contraction was produced or not. If there was no contraction at the cessation of the current, the muscular fibres suddenly regained their previous length, and if there was a contraction, the fibre appeared to be even longer than before, after the contraction had passed off. None of these phenomena, however, were observed, if instead of the muscular fibres the nerves were enclosed in the circuit.*

Inherent muscular irritability has, therefore, been proved:

1. By microscopic observations of Mr. Bowman, showing a partial contraction of muscular fibres which have been entirely isolated from every extraneous tissue.

2. By the experiments of Bernard, Kölliker, and myself, with woorara, which kills the motor nerves and leaves the muscles intact.

3. By the microscopic observations of Dr. Wundt, showing an action of the closed continuous current upon the muscular fibre when the electrodes are directly applied to the muscles, and no such action if the stimulus be conveyed to the muscles by the instrumentality of the nerves.

Thus it is evident that by the electric current the molecular equilibrium of the muscles may be directly disturbed, just as well as the molecular equilibrium of the nerves. As soon as the equilibrium of either motor nerves or

* Die Lehre von der Muskelbewegung. Braunschweig, 1858, p. 122.

muscles is disturbed, contractions are observed. The contractions produced by applying the electric current directly to the contractile tissue of the muscles, present, however, certain peculiarities which are worth noticing.

If the current be directed to a motor nerve, the whole substance of all the muscles which are animated by the nerve enters into contraction; but if the current be directly applied to a muscle, only those fibres are seen to contract which are traversed by the current; and if we wish to produce a contraction of the whole substance of a muscle, the electrodes must be placed, one at the upper and the other at the lower end of the muscle. Besides, a current of greater intensity is required if we wish to produce muscular contractions without the intervention of nervous filaments, than is necessary if we cause contractions by excitation of the motor nerves. *Hence we may conclude that the molecular equilibrium of the motor nerves is more easily disturbed by the electric current than the molecular equilibrium of the muscles.*

If a muscle is caused to contract by placing the electrodes upon the belly of the muscle, the contraction is composed of two elements; viz. contraction by direct excitation of the muscles, and contraction by excitation of the nervous filaments which are mixed up with the muscles. It is evident that muscular contractions will be most easily produced if such points are touched by the electrodes where the motor filaments are superficial; but if a sufficiently strong current be employed, contractions will be induced, even if the electrodes are placed on such

points of the surface of the muscle, where dissection does not show the existence of motor filaments.

Many interesting facts have been evolved from the application of electricity to the study of the functions of the muscles of the living body; and it has thus become possible to create a kind of living anatomy. Dr. Duchenne, of Paris, first undertook systematic researches of this kind, which have led to several important discoveries.

It is true that the deep strata of the muscles, covered by the superficial ones, will not clearly exhibit their contraction. But here, pathology has seconded physiology. It is chiefly muscular atrophy which, by destroying the superficial muscles, takes away the impediments to the passage of the electric current, and thus helps to the knowledge of the function of every muscle in the living body. Many of the theories on the functions of the muscles formerly adopted have thereby fallen to the ground. As one of the most remarkable facts now established, I may mention that the muscle extensor communis digitorum has no influence whatever on the extension of the second and third phalanges, but only on the first, that it is, in fact, the little interossei and lumbricales that extend the second and third phalanges and bend the first. Also that the muscles flexor sublimis and profundus bend the second and third phalanges, but not the first. This is confirmed by many pathological facts, chiefly in lead-palsy and muscular atrophy; in lead-palsy the extensor digitorum is paralyzed, but not the lumbricales and interossei. Therefore, in lead-palsy, the power of ex-

tension of the second and third phalanges remains in all its integrity; and only the first phalanges cannot be extended. On the other hand, when the extensor digitorum is not at all paralyzed, the hand has sometimes the form of a claw, the interosseous spaces are deeply hollowed, the hand is very thin, the first phalanges are extended, but the second and third are bent. This condition of the hand is due to paralysis and atrophy of the lumbricales and the interossei, and is often cured by the local application of the electric current to the afore-named muscles.

Dr. Duchenne has given special study to the function of the muscles of the face, in order to arrive at a knowledge of the mechanism of physiognomical expressions; for it is only the muscles which are put in action by thoughts, passions, and character; they preserve, during muscular repose, the predominance of tonic force, and stamp on every physiognomy its peculiar impression. If there was not in every face this tonic predominance of one or other muscle, all physiognomies would be nearly alike, as the muscles have the same direction, insertion, and strength, and the bones only differ from each other in volume. It is true that, although the facial muscles have only a very small surface, electricity can be localized in each one singly, so as to produce isolated contractions. The way to show most clearly the part every muscle takes in the different physiognomical expressions, is to electrify the muscles of the face of a man just dead, and whose muscles yet retain their excitability; for the living man, when electrified, always mixes involuntary move-

ments with the contraction of the electrified muscle; an impediment, of course, to the observation of the individual action of the muscles.

The frontal muscle, when slightly contracted, cheers up the face; when more contracted, it expresses doubts, surprise; and when in the highest degree of contraction and united with other muscles, it gives the expression of an agreeable surprise or of terror; it also wrinkles the forehead, and when it is paralyzed the wrinkles disappear.

The pyramidales nasi, which are in intimate relation with the frontal muscle, and therefore considered by many anatomists as identical with it, are nevertheless the antagonist of the frontal muscle; they give a sad expression, and, when more contracted, a threatening one. It forms a striking contrast to see these two opposite movements produced in so small a space as the level of the eyebrows.

Isolated contraction of the *orbicularis palpebrarum* and *corrugator supercilii* expresses reflection; and when united to the pyramidalis, they express malice. *The platysma myoides* gives an expression of pain; united with the frontal muscle, it expresses terror; and, with the pyramidalis, rage. Contraction of the *triangularis nasi* gives the expression of lust. The *zygomaticus major* always expresses mirth, from simple smiling to the most extravagant hilarity; united with the frontalis, it gives the expression of an agreeable surprise; with the *platysma myoides*, the sardonic laugh: the *zygomaticus minor*, on the con-

trary, gives a melancholy air. The *levator alæ nasi*, and *labii superioris* is the real weeping muscle of children, and produces a very ugly grimace. By the contraction of the external fibres of the *orbicularis oris*, the lips are protruded as for kissing and whistling; the internal fibres press the lips against the teeth, as is done, for instance, by players on the clarionet, for pinching the reed of their instrument between the lips. The *levator menti* is the only muscle in action in persons who repeat their prayers inaudibly, as is often seen in Catholic churches. The *triangularis oris* expresses sadness; in children it is the precursor of tears; in the maximum of its contraction it expresses disgust.

The *deltoid* muscle, when galvanized, abducts the humerus, but does not elevate it above the horizontal line. If the anterior fibres only are galvanized, the arm is at once elevated and directed forwards and inwards; if the middle fibres are galvanized, the arm is directed outwards; while, by galvanization of its posterior fibres, the arm is carried backwards, and the hand raised behind the back. The deltoid muscle is very frequently attacked by wasting palsy.

If the inferior portion of the *trapezius* be galvanized, the base of the scapula is approached to the spinous processes, and the inferior angle of the scapula drawn downwards; this portion tends by its tonic contractility to keep the base of the scapula at a distance of about 2½ inches from the median line. If the *middle portion* of the trapezius be galvanized, the scapula is elevated, and its in-

ferior angle removed from the median line. Finally, if we galvanize the *clavicular portion* of the trapezius, the head is drawn towards the side acted upon and a little backwards, so that the chin is turned towards the opposite side; at the same time the clavicle is raised. If the clavicular portions of both trapezii receive the electric stimulus, the head is reversed backwards. The clavicular portion of the trapezius is very excitable, as it gets nervous fibres from two sources, viz. from the spinal accessory, and from the cervical plexus.

The *latissimus dorsi*, when galvanized, draws the arm downwards and backwards; the scapula is at the same time approached to the median line, but it is not raised.

The *rhomboid muscle* is only accessible to the electric current if the trapezius is destroyed. If it be then galvanized, the scapula is raised; at the same time it is so turned that the inferior angle is nearly in the same line with the external angle. The rhomboid, by its tonic contractility, fixes the base of the scapula against the thorax. If it be destroyed, the base of the scapula is removed from the thorax, and becomes prominent under the skin, so that a cavity is formed between the base of the scapula and the spine.

The *serratus magnus* is chiefly inspiratory muscle; it elevates the ribs from which it arises; and contributes besides to lift the humerus. The arm is lifted above the horizontal line by the joint action of the deltoid, the serratus magnus and the middle fibres of the trapezius. The serratus magnus also tends to keep the external angle

of the scapula in its normal position; the weight of the upper extremity tending continually to depress the external angle of the scapula. Both the trapezius and the serratus are opposed to this depression being effected. If the trapezius be atrophied, the external angle of the scapula is depressed, while at the same time its inferior angle is raised and approached to the spinous processes; if the serratus be also attacked by wasting palsy, the external angle is still more depressed; the inferior angle is raised to the level of the external angle, and it moves at a considerable distance from the thorax.

Generally the most striking result of electro-muscular contractions is, an *increase of heat and bulk*, in the parts acted upon. On this point Dr. Ziemssen, of Greifswald, has made a series of experiments on healthy as well as on paralyzed muscles, and has found that the augmentation of heat is proportional to the force of the contraction, and the length of time it continues. These contractions excite a sensation of heat in the shortened muscles, and are accompanied by an increase of bulk, which may be $\frac{1}{4}$ of an inch in the fore-arm, if the extensor muscles of the fore-arm are galvanized; and from $\frac{1}{2}$ an inch to an inch in the thigh, if the rectus is galvanized. By means of the thermometer, and also by the hand, we are able to distinguish the heat communicated from the galvanized muscles to the skin which covers them, from the normal temperature of the surrounding parts. If the skin and the thermometer be covered by flannel, or any other substance which is a bad conductor of heat, the temperature

rises more rapidly, and to a higher degree, than if they are uncovered. In both cases the heat produced is the same, and the apparent difference in the latter instance is merely due to the exclusion of air from the galvanized part, by which means the heat generated is longer preserved.

The decrease of temperature, after the electric excitation has ceased, is slow and regular; but it is more rapid when the skin is exposed to the atmosphere than when it is covered.

The difference in the heat of the skin before and after the electric excitation of the muscles is in many cases 5° to 6° F.

I have also made a number of experiments regarding the heat developed by electro-muscular contractions, especially on paralytic patients, which have led to the following conclusions:

1. *The heat observed after the application of induction currents to the muscles is in no way due to the action of the current upon the skin.* This we may theoretically infer from the fact that, although the electrodes are in direct contact with the skin, the electric current, if applied by well-moistened electrodes, does not act on the skin at all, but traverses it, and penetrates to the muscles as the best conducting substance. This proposition is also affirmed by pathological experience. Some time ago I galvanized a patient suffering from lead-palsy; in this case the contractility of the extensor muscles of the *right* fore-arm was quite abolished, while a certain contractility still re-

mained in the extensor muscles of the *left* fore-arm. On applying induction currents for five minutes to the extensors of the left fore-arm, the temperature was increased from 89° F. to 91°,5 F., while the same operation made on the extensors of the right fore-arm did not produce any increase of heat, but on the contrary, the heat, which had been 87°,5 in the right fore-arm before the application of electricity, was only 86° F. afterwards; this diminution of temperature being due to the contact of the skin of the fore-arm with the atmosphere.

2. *The increase of heat observed after the application of induction currents to the muscles, is not due to a greater afflux of blood to the arteries and veins*, for these are not expanded, but constricted by direct Faradisation, and consequently contain less blood after having been acted upon by induction currents, than they do in their normal physiological condition.

3. *But the increase of heat observed after the application of induction currents to the muscles, is due to an augmentation of those chemical changes which are continually going on in the tissue of a muscle, and which constitute the nutrition of the muscle.* The solid structure of a muscle is imbibed by a fluid, the composition of which is variable; muscular fluid taken from a muscle which has been at rest presents a neutral re-action, but when induction currents have been applied to a muscle, the fluid presents an acid re-action, in consequence of an augmented absorption of oxygen, and the formation of carbonic acid. If we measure the quantity of oxygen

absorbed, and carbonic acid exhaled, by the muscular substance of frogs' thighs which have been skinned and suspended in vessels filled with air or oxygen, we find that if some of the muscles are galvanized, and the others not—the quantity of the gases absorbed and exhaled by the galvanized muscles is more than double that absorbed and exhaled during the same time by the quiescent muscles. The same differences occur in the living muscles of man, and, by the augmentation of chemical changes, the heat is increased, more blood is attracted to the capillary vessels of the muscular substance, whereby the bulk of the muscles is increased; and the very fact that there is more blood attracted to the tissue, produces again an increase in the nutrition of the parts.

4. *In regard to the direction of the current*, as influencing the increase of heat, I have generally remarked a slight difference in favour of the *direct* current—moving from the centre to the periphery—in healthy muscles; and an equally slight difference in favour of the *inverse* current—moving from the periphery to the centre—in paralyzed muscles. I need not mention that in such comparative experiments the current applied was always of the same intensity, equally rapidly interrupted, and directed to the same muscles for the same length of time.

5. *As to the greater or less rapidity of the intermittences used*, I have invariably observed that the heat was increased more rapidly and to a higher degree, if a rapidly interrupted current was employed, than if the intermittences were slow.

It appears to me that these results tend to contribute towards a satisfactory solution of the vexed question, "What are the effects of galvanism on paralyzed muscles?"

V. *Action of the electric current upon the sentient nerves.*

Sparks taken from the common electrical machine while in action, produce a sharp pungent sensation in the skin. The discharge of a Leyden jar through the human body produces a peculiar stunning sensation, known as the electric shock. A continuous galvanic current, when applied to the skin, excites a sensation of heat and pain not only at the commencement and at the cessation of the current, but also during the whole time that the circuit remains closed. If the action of the current be kept up for a certain time, the pain disappears, and a feeling of numbness is perceived. Marianini has taken much trouble in investigating the influence which the direction of the current, when applied to sentient nerves, has in the production of the physiological effects; and he arrived at the conclusion that the sensation, caused by the application of the continuous current, is strongest on making the inverse, and on breaking the direct current; while the contrary takes place when the motor nerves are acted upon, as muscular contractions are more easily excited on making the direct and on breaking the inverse current.* Therefore, if mixed nerves are excited, the phenomena will be as follows:

* Mémoire sur la secousse qu' éprouvent les animaux, etc., in Annales de Chimie et de Physique. Paris, 1829. Vol. xl., p. 225.

Direct.		Inverse.	
Making.	Breaking.	Making.	Breaking.
Contraction.	Sensation.	Sensation.	Contraction.

If induction currents are caused to act upon the skin, sensations are produced, varying according to the intensity of the current, and passing through all intermediate degrees, from a little tickling, burning, or pricking, to the acutest pain, but these sensations almost entirely cease after the circuit has been broken. Besides, the physiological effect is different according to the greater or less velocity of the intermittences. A rapidly interrupted induced current has more effect on the sentient nerves than a slowly interrupted current; the reason of this is, that sentient nerves have the property of feeling the effect of impressions some time after they have been acted upon. Thus, if a sentient nerve, in its normal condition, is subjected to the action of a single induced current of low tension, the sensation caused by it will be trifling; but if a second shock rapidly succeeds the first, the sensation will be much more marked; because the sentient nerve is no longer in its normal physiological condition when it receives the second shock from an induction apparatus, but in an excited state; a third shock will have still more effect than the second, and so on. Therefore, it is easy to understand why the sensations produced by the interrupted current increase in direct proportion to the velocity of the intermittences; if a hundred shocks are applied to a sentient nerve within a second, the effect will

be quite different from that produced by the same number of shocks if applied within ten minutes. If the velocity of the intermittences is very great, and an interrupted current sent for a certain time through the trunk of a nerve, a maximum of excitation will be reached; after which the excitability of the nerve will be diminished, and a direct reduction of its sensibility follow.

The question, if hyperæsthesia might be reduced and anæsthesia caused by electricity, has of late very much occupied the professional mind. It was alleged that teeth might be extracted without pain by the aid of galvanism, and that even in severe surgical operations electricity might be of service as a local anæsthetic. Dr. Richardson was the first who contradicted these assertions, and contended in a paper on local anæsthesia and electricity,* that the electric current in its local application has no effect whatever in reducing sensibility; he suggested that if by a powerful shock to the whole body feeling be destroyed, such is only the case, because the shock destroys at once consciousness, whilst the current, if locally applied, restores rather than destroys sensibility. He then related various experiments made by himself on his fingers by means of the Leyden jar, the continuous and the interrupted current. Thus he charged twenty Leyden jars, and discharged them either in combinations, or one after the other, in rapid succession through one of his fingers. The shocks were painful to bear, and when many were given, the last was felt as severely as the first,

* Medical Times and Gazette, Sept. 11, 1858.

and the finger was afterwards as sensitive to the prick from the point of a lancet as it had been before. He tried the local effect of the continuous current, but with as little success; he then passed the electro-magnetic current through one finger, sometimes submitting the part for periods of an hour, or more, to a gentle current; at other times increasing its power till the pain produced was scarcely endurable; but in every case without the slightest effect in removing sensibility.

Long before the subject of electrical anæsthesia agitated the professional mind, I had made a number of experiments in order to arrive at a distinct notion of the benumbing effects of electricity, the possibility of which had been both denied and maintained by many observers. The result of these experiments has been, that a direct reduction of sensibility in a nerve can be accomplished in the following way: if a continuous, or a rapidly interrupted induced current of medium intensity is sent through the trunk of a nerve,—say the ulnar, or the sciatic, by placing one moistened conductor connected with the positive pole to a point of the skin where the trunk of such nerve is superficial; and another moistened conductor connected with the negative pole to any of the terminal branches of the nerve, and the action of the current be kept up for a quarter of an hour, the pain which is excited by this proceeding becomes much less, after a certain time, than it was at the beginning of the operation, and a feeling of numbness is produced in the limb. I do not mean to say that sensibility can be entirely destroyed

by this local application of electricity, but I am quite satisfied that it is notably diminished by it. The result is much more striking, if there is a morbid increase of sensibility in a nerve, as is the case in neuralgia, than if a nerve in its normal state is acted upon.

In a very able paper on the therapeutic uses of electricity, in the British and Foreign Medico-Chirurgical Review for January, 1859, it is contended that for the relief of hyperæsthesia a current of very high tension is necessary; with this my experience disagrees, as I have seen in many cases, that a current of medium intensity is quite capable of producing the desired result, provided the action of the current be kept up for a certain length of time. If the nerve is in an hyperæsthetic state, I have seldom found it necessary to prolong the application of the current beyond five or six minutes; but to effect a direct reduction of the sensibility of a nerve in its normal condition, the current must act for not less than a quarter of an hour; and in some persons even a longer time will be required.*

* After the publication of my short note on anæsthesia and electricity, in the Medical Times and Gazette for September 18, 1858, I was desired by Dr. Richardson to operate upon himself, as he wished personally to experience the benumbing effect of the electric current applied to the trunk of a nerve. I consented to his request, and applied a rapidly interrupted current to Dr. R's. ulnar nerve, placing one moistened conductor between the olecranon and the internal condyle, while the other conductor was placed in his hand. I began with a current of low tension, such as was not powerful enough to produce contraction of the muscles animated by the ulnar nerve. After this current had acted for a few minutes, I increased the intensity, so that a strong flexion of the fourth and little finger was produced. The action of this current was

Independently of the direction of the current, the negative pole of a voltaic pile and of induction machines has a stronger effect on the nerves of the skin than the positive pole. This circumstance may even enable us to tell the direction of the current in an electrical apparatus, provided that certain precautions be taken. It is necessary, in the first place, that similar or nearly similar parts of the skin should be acted upon; since the epidermis is not of the same thickness on all parts of the body, and electricity is less strongly felt where the epidermis

at first painful to bear, and the pain continued to increase during the first few minutes of application; but it soon became less, so that I could further increase the intensity of the current, without causing much inconvenience to Dr. R., who became again gradually insensible to the stronger shocks. The intensity of the current was then increased a third, fourth and fifth time, and every additional increase was felt distinctly and immediately, but after a certain time the pain excited by very severe shocks was comparatively little. At last the normal sensibility of the ulnar nerve was so much diminished, that a current of such a high tension was borne without inconvenience by Dr. R., as would have been perfectly unendurable in the beginning of the experiment. Besides, Dr. R. mentioned a sensation of numbness in the tips of the fourth and little finger, and that he did not feel the board upon which his fingers rested. The intensity of the current was then diminished, and Dr. R. was now quite insensible of shocks which had caused him much inconvenience previously. After the current had ceased to act, numbness was still perceived by Dr. R. in his arm for a certain time. It is therefore obvious, that a direct reduction of the sensibility of the ulnar nerve was accomplished by electricity; but although the intensity of the current was very high, and the velocity of the intermittences very considerable, no complete anæsthesia of the skin was produced; as the skin of the hand is not only animated by the ulnar, but also by the median and radial, nerves. During the experiment just related, Dr. R. was always able to feel the prick of a pin in his fingers. Dr. R. has lately published experiments on producing anæsthesia by means of narcotics and the continuous current; but it is evident that in this case it is the narcotics that do the work, and not electricity.

offers much resistance to the passage of the current; besides, the distribution of sentient nerves is not equal in all parts of the skin, and electricity will, *cæteris paribus*, be felt more on such parts of the skin, which are richly endowed with nervous filaments, as is the face, than on parts which possess less abundant ramifications. It is also essential that the size and condition (moist or dry) of the conductors should be equal, since a current of the same power possesses more density if conveyed by a small electrode, than if transmitted by a conductor with large surface; and a moist conductor will act less on the skin and more on the muscles, while a dry conductor will act more on the skin and less on the muscles. If, however, the precautions just described be taken, it is easy to distinguish the negative pole from the positive pole, by the stronger sensation excited by the former. Frequently it happens that no sensation whatever is produced by the application of the positive pole, and the negative pole is the only one that is felt. I have verified this fact on many of my patients, who have almost invariably been able to tell the direction of the current, after they had been informed that the strongest sensation is excited at the negative pole.

The difference alluded to is especially remarkable if the feet of the patient are plunged in two basins filled with water, and connected with the poles of the apparatus: in this instance the current is always felt more strongly in that limb in which it is upward. If the hands are plunged into the basins, this effect is not quite

so evident, as the epidermis of the right hand is generally thicker than that of the left, in consequence of the greater use made of the right hand. Thus, if the current is upward in the left arm, the sensation will be much stronger in the left than in the right hand; but if the current be upward in the right, the sensations will be nearly the same in both hands, as the more powerful stimulus conveyed to the right hand is compensated by the greater resistance of the epidermis to the passage of the current.

VI. *Action of the electric current upon mixed nerves.*

The phenomena produced by the Galvanization of mixed nerves are due to the excitation partly of the motor filaments and partly of the sentient fibres, of which the mixed nerves are composed. With regard to the direction of the current, I may mention, that by the application of the direct current powerful muscular contractions are produced, and comparatively little pain; if the inverse current be used, the contrary takes place, viz. the muscular contractions are not very strong, and more pain is experienced.

VII. *Action of the electric current upon the sympathetic nerve.*

The first experimental researches on the function of the sympathetic nerve were undertaken in 1727, by M. Pourfour du Petit, who found that after the section of the cervical filament of the sympathetic nerve the following phenomena are observed: constriction of the pupil; flattening of the cornea; redness and injection of the conjunctiva; be-

sides, the secretion of the palpebral mucus is increased, the eyelids are partially closed, and the third eyelid or nictitant membrane becomes prominent and advances upon the eye-ball. If the animals continue to live a certain time after the operation has been made, the eye appears to be smaller, and in reality shrinks; it is drawn backwards into the orbit. The experiments of M. Pourfour du Petit were repeated and confirmed by Dupuy, Breschet, and Dr. John Reid. In 1846, M. Biffi, of Milan, observed that if the pupil has become constricted after the section of the cervical sympathetic nerve, it can again be dilated if the cephalic end of the nerve be galvanized.

In 1852, Professor Claude Bernard published his important experimental researches on the physiology of the sympathetic nerve.* He pointed out that after the section of the nerve, or after the destruction of the superior cervical ganglion, besides the phenomena noticed by M. Pourfour du Petit, the following are produced: a more or less marked constriction of the nostril and of the mouth of the corresponding side; besides an increase of the circulation of the blood, together with an augmentation of heat and sensibility in the head. He also observed that if the cephalic end of the sympathetic nerve be galvanized, all the phenomena observed after the section of the nerve equally disappear, and are even exaggerated

* Sur l'influence du nerf grand sympathique sur la chaleur animale; in Comptes rendus, etc., 29 Mars, 1852; and Comptes rendus de la Société de Biologie, Octobre et Novembre, 1852.

in an inverse direction. Not only does the constriction of the pupil produced by the section of the sympathetic nerve disappear by Galvanization, but the pupil becomes even larger than that of the opposite side; the eye, which had been drawn backwards, protrudes beyond the orbit; the temperature, which had been notably increased, falls below its average standard, and the conjunctiva, the nostrils, the ears, which had been red and injected, become quite pale again. But as soon as the galvanization is discontinued, all the phenomena, previously observed after the section of the nerve, gradually re-appear. We may, however, cause them to disappear a second and even a third time by repeated applications of galvanism to the cephalic end of the nerve. If a drop of ammonia is applied to the conjunctiva of a dog, in which a section of the nerve has been made, the pain experienced by the animal will oblige it to keep its eyelids firmly closed; but if the upper end of the sympathetic nerve is galvanized, the dog, notwithstanding the pain he experiences, is no longer able to keep them shut; but opens them again, while at the same time the redness of the conjunctiva, produced by the caustic, is diminished, and soon entirely disappears.

Experiments of the same kind have afterwards been made by Dr. Augustus Waller, at Birmingham, Professor Budge, at Greifswald, Professor Schiff, at Berne, and Dr. Brown-Séquard; all of whom have added new facts to those already known about the physiology and pathology of the sympathetic nerve, which may be resumed as follows:

After the section of the cervical sympathetic nerve almost all the muscles of the eye, of the angle of the mouth, and of the nostril, are contracted; the ear is kept erect; the quantity of blood in the ear and in the whole corresponding side of the head is notably increased; the arteries are fuller, and seem to beat with more power; the temperature is augmented, in some instances to 11° or 12° F.; poisonous and other substances, which are deposited in equal quantities on both sides, in the subcutaneous cellular tissue of the face or at the base of the ear, are more rapidly absorbed on that side where the section has been made; chloroform destroys sensibility later there than on the opposite side; rigor mortis appears later, and lasts longer; putrefaction commences later, and the current proper of the muscles is strong, when compared to the current proper of the muscles on the other side.

By the Galvanization of the cervical sympathetic nerve the following phenomena are produced: dilatation of the pupil; opening of the eyelids; contraction of the blood-vessels; diminution in the quantity of the blood; decrease of temperature and of sensibility; dryness of the con·junctiva and cornea; the current proper of the muscles is very weak; the excitability of the motor and sentient nerves of the iris, and of the muscles, and the contractility of the arteries disappear sooner after death than on the other side; and cadaveric rigidity and putrefaction commence also sooner.

Almost all these phenomena are due to the paralysis of the blood-vessels which follows the section of the sym-

pathetic nerve, and in consequence of which more blood passes through these vessels in a given time. Hence an increase of the vital properties of the contractile tissues and the nerves. Almost all the phenomena observed after the section of the sympathetic nerve may be observed, if the quantity of the blood, circulating in the blood-vessels of the head in a given time, is increased by any means whatever; thus the hanging down of an animal, by holding it by its hind-legs, will produce a strong congestion in the head, and almost all the effects of the section of the sympathetic nerve. Once a greater afflux of arterial blood having been induced, this becomes again a cause of the attraction of more blood; on the other hand, the blood is attracted by the increase of temperature, and the more considerable chemical changes thereby caused in the tissues.

I now proceed to describe the phenomena observed after the direct Galvanization of the ear, which differ according as a section of the cervical sympathetic nerve is made or not. After the section of the sympathetic nerve the ear becomes hot. If the ear is then galvanized by placing one pole of an induction apparatus to the base of the ear and the other to its extremity, so that the ear is traversed by the current in its large diameter, the temperature is not lowered, as is the case if the cephalic end of the sympathetic nerve be galvanized; but the heat in the ear is thereby further increased. On the contrary, if no section of the cervical sympathetic nerve has been made, and the ear is galvanized, the temperature of the

part is lowered. Thus Bernard galvanized the ear of a rabbit, in which he had cut the left sympathetic nerve, while at the right side no such operation had been made; and found that if the left ear was galvanized, a rapid and considerable increase of heat took place; but that, if the right ear was galvanized, just as rapid a diminution of heat was produced. According to Bernard this is to be explained in the following way: on that side where the sympathetic nerve has been cut, the elevation of temperature results from the circumstance that, under the influence of the pain, the heart acts more vigorously upon the arteries of the ear which are relaxed, in consequence of the section of the sympathetic nerve; while, on the other side, where the nerve has not been cut, galvanism produces an excitation of the sentient nerves, which is transmitted to the spinal cord and by reflex to the sympathetic nerve; hence the vessels of the ear are constricted, and the action of the heart cannot produce the same results as on the other side, where no reflex action from the spinal cord to the sympathetic nerve is possible. This is proved by the following experiments: if the auricular nerve, which takes its rise from the cervical plexus, and which transmits the reflex action from the ear to the spinal cord, be cut, the temperature of the ear can no longer be diminished by direct Galvanization of the ear; but we observe again a decrease of temperature in the ear after the section of the auricular nerve, if the central end of it is galvanized; whereby again a reflex action to the cord and thence to the sympathetic nerve is rendered possible.

If the inferior cervical ganglion of the sympathetic nerve is galvanized, the pulse of the heart is accelerated; the same is observed if the cardiac branches are subjected to an electric current; while, if the vagi are galvanized, the action of the heart is stopped. This was first observed by Professor Weber, in 1846.

In 1856 Pflüger discovered, that the splanchnic nerves have a similar influence upon the movements of the intestines, as the vagi upon the action of the heart.* He found that if the splanchnic nerves, which take their rise from the six lower dorsal ganglia of the sympathetic nerve, are galvanized, the peristaltic movements of the small intestines are almost immediately arrested. Hence Pflüger concluded that there is a peculiar set of nerves which has the function of diminishing or arresting the peristaltic movements; this set of nerves he called the inhibitory system. Mr. Lister † has lately experimented upon the same subject, and has found that the inhibiting influence is only produced if a strong electric current is applied to the splanchnic nerves; but that there is an increase of function in them if they are excited by a mild current.

VIII. *Action of the electric current upon the contractile fibre-cells.*

The electric current has a remarkable action upon the muscular fibre-cells. They respond more readily to the

* Ueber das Hemmungs—Nervensysten für die peristaltischen Bewegungen der Gedärme. Berlin, 1856.

† Preliminary accoun', etc., in Proceedings of the Royal Society. Vol. ix. No. 32.

induced current than to the continuous current; and if the continuous current be applied to them, contractions are observed, not only at the commencement and at the cessation of the current, as is the case with the voluntary muscles, but also while the circuit remains closed. The intensity of the current employed, and the length of time during which the action of the current is kept up, determine the intensity and duration of the movements induced in the organic fibre-cells.

If an electric shock is applied to a voluntary muscle, it immediately contracts, and then as quickly relaxes; while the movements induced in the muscular fibre-cells by galvanism are not observed simultaneously with the application of the electric stimulus, but only a certain time after the current has acted upon the tissue. The only exception from this rule is made by the iris, which is, in this respect, similar to the voluntary muscles. Besides, the motion once excited in the fibre-cells, continues for a certain time after the cessation of the current; and is not confined to those parts to which the electric current has been directly applied, as is the case with the voluntary muscles, but is also propagated to other parts of the same tract. Finally, the movements of the fibre-cells caused by galvanism are only induced in an order which corresponds to the physiological purpose; thus, by an electric excitation of the intestines only peristaltic movements are induced, but never movements from the rectum to the mouth; if the uretheres are excited, the movements are from the kidneys to the bladder, but

never in the opposite direction; whatever may be the intensity and the direction of the current, and whatever may be the point of the tract to which the electrodes are applied.

Experiments of this kind have been made not only on living and dead animals, but also on the corpses of executed culprits. Researches of the latter kind have been undertaken especially by M. Nysten,* during the first French Revolution, when the guillotine furnished a large material for observations of this kind; and more recently by Professors Heule, Kölliker, Gerlach, Harless, and others, in Germany.† The results of these experiments are somewhat at variance with each other; but this is due to the circumstance that some have employed the continuous, others the induced, current; and that those who employed the continuous current, have, in some instances, made use of very feeble batteries.

Iris.

As I have already stated, the iris, when acted upon by the electric current, does not contract slowly, and does not remain in a contracted state after the cessation of the current; but, like the voluntary muscle, it contracts rapidly, and these contractions cease immediately when the circuit is broken. By the galvanization of the iris, dila-

* Nouvelles expériences galvaniques faites sur les organes musculaires de l'homme et des animaux à sang rouge. Paris, An. xi. (1803.)

† Ueber einige an der Leiche eines Hingerichteten angestellte Versuche und Beobachtungen; in Zeitschrift für wissenschaftliche Zoologie von Siebold und Kölliker. Vol. iii., p. 39.

tation as well as constriction of the pupil may be produced, according as the current acts upon the dilator or the constrictor muscle. A constriction of the pupil is observed, if one pole is directed to the cornea, and the other one to any point of the head or face; by this arrangement the circular fibres of the iris (sphincter pupillæ) are put in action. Thus Kölliker observed, that on applying one pole of an induction apparatus to the lower jaw, and the other to the cornea, of the body of a man who had been executed shortly before, the pupil became constricted equally and rapidly, at the same time there was a distortion of the features; but as soon as the poles were removed the pupil was again rapidly dilated. The same phenomenon was noticed in both eyes, and the experiment was repeated several times with the same result. A constriction of the pupil is also perceived, if one metal of a single galvanic pair is placed in the nose and the other one on the tongue; it is, however, necessary to the success of experiments of this kind, that they should be made in a room where only so much external light is admitted as is sufficient for discerning the size of the pupil. It is then easy to observe that a constriction of the pupil takes place each time the metals are brought in contact with each other.

If the poles of an induction apparatus, or of a single galvanic pair, are directed to the edge of the cornea, the radiar fibres of the iris (dilatator pupillæ) are excited, and the pupil is, therefore, dilated. The same is observed if the poles are directed to the sclerotica. Besides, I may

mention that when the poles are applied to the upper and the lower part of the cornea, the pupil assumes the shape of a lying oval; and that when the electrodes are placed to the right and left side of the cornea, the pupil assumes the form of a standing oval.

Intestines.

The fibre-cells of the intestines respond very readily to the galvanic stimulus. Aldini observed that when a zinc plate was placed in the mouth of an ox recently killed, and a piece of silver in the rectum, and both metals were connected by means of a wire, the abdominal muscles of the animal were convulsed and the fæces discharged. This experiment was repeated by M. Achard, of Berlin, on himself, who experienced, almost immediately after the circuit had been established, pain in the pelvis, and soon afterwards the contents of the bowels escaped.

If the *salivary glands* are directly galvanized, we do not observe a flow of saliva; but Professor Ludwig, of Vienna, has shown* that if the lingual and auriculo-temporal nerves, the chorda tympani, and the posterior parotideal branches of the facial nerve are galvanized by induction currents, an abundant flow of saliva takes place; and Professor Claude Bernard has proved,† that if the nerves just named are galvanized, the blood-vessels of the salivary glands become enlarged, and that this dilatation

* Lehrbuch der Physiologie des Menschen. Heidelberg, 1853. Vol. ii. p. 59.

† Journal de la Physiologie de l'homme. Paris, 1858, Oct., p. 649.

of the blood-vessels is due to a greater attraction of arterial blood developed in the tissues. If the sympathetic nerve is galvanized, the salivary secretion is not induced, but arrested. The amount of saliva which may be collected in a very short time from the salivary glands, if the nerves above named are galvanized, by far surpasses the volume of the glands themselves, so that it cannot be supposed that the saliva is simply squeezed out of the gland; but it is secreted in the gland at the very moment when galvanism is caused to act on the secretory nerves; the excretion of the saliva is effected by the same forces which attract the blood to the glands, not by the tissue of the glands, since the elementary substance of the glands has no inherent contractile power. Professor Bernard is inclined to assume that the capillaries possess two properties, one of contraction, and the other of dilatation; and that either of these properties is put in play by a peculiar set of nerves.

Galvanization of the *œsophagus* in man produces a remarkable contraction of the longitudinal, as well as of the circular, fibres; and if the action of the current be kept up for a certain time, the contraction is no longer limited to the part directly operated upon, but proceeds downwards towards the stomach. In man and most of the mammalia, the œsophagus is composed of both animal muscular fibres and organic fibre-cells, so that its contraction by galvanism resembles neither the contraction of voluntary muscles, nor that of pure fibre-cells. In birds the œsophagus consists exclusively of fibre-cells; therefore

the motion excited by galvanism in the œsophagus of birds begins slowly, and lasts some time after the cessation of the current. In the rodentia or gnawers the œsophagus consists of animal muscles only, and if it be galvanized, we observe a rapid contraction, and at the cessation of the current just as rapid a dilatation.

The *stomach* also responds well to the electric stimulus, and we observe after galvanization of it a shortening of both the longitudinal and the transverse diameter; the direction of the movement is always from the cardia to the pylorus.

The small intestines are particularly excitable by galvanism. If the cavity of the abdomen is opened in animals recently killed, powerful contractions of the intestines are observed, which are produced by the contact of these tissues with the air. After a certain time these contractions cease; and if then an electric current is caused to act upon the small intestines, they are again seen to contract strongly, and the contents of the bowels are propelled towards the rectum. If the electrodes be placed very near each other on any point of the intestines, and are shortly afterwards rapidly removed, we observe a constriction of the canal on that particular point to which the electrodes have been directed. This constriction reaches its maximum a short time after the electrodes have been removed, and then slowly disappears. It generally extends a little above and below the point where the electrodes have been placed; and it is most striking in the duodenum, while it is not very remarkable in the

cœcum. The *colon* and the *rectum* respond well to the electric stimulus, although not so much as the small intestines.

If the *gall-bladder* is acted upon by electricity, it is seen to contract and to void the bile into the duodenum. If the electrodes are placed very near each other, a constriction is produced in the gall-bladder, which may be so remarkable as to divide that organ in two distinct parts which do not communicate with each other.

The *spleen* of most of the mammalia contracts very fairly under the influence of the electric current: as to the contractility of the spleen of man, there is much difference of opinion amongst the observers. Thus Kölliker, Dittrich, and Gerlach deny the contractility of the spleen of man; while it is positively affirmed by R. Wagner, Harless, and Claude Bernard that they have seen contractions of the fibre-cells of the spleen: this is probably due to the circumstance, that Kölliker used a feeble continuous current, while Wagner and Bernard employed a powerful induction apparatus.

The *uretheres* contract very energetically when acted upon by the electric current; they are at the same time shortened and constricted, and the contractions always proceed in the direction from the kidneys to the bladder. These contractions continue long after the galvanization has ceased.

The *bladder* contracts vigorously when galvanized; the *vas deferens*, the *epididymis*, and the *tunica vaginalis propria* are also not devoid of contractility. The uterus

may be contracted by the application of galvanism, whether it be in the gravid state or not; Weber has observed partial contractions of the uterus in bitches and rabbits; that the human uterus in the gravid state contracts *in toto*, when galvanized, is confirmed by clinical experience.

Quite recently Dr. Mackenzie has made some experiments on the influence of the electric current upon the contractile substance of the uterus.* He exposed the gravid uterus of a pregnant bitch, and by directing the electro-magnetic current to it, perceived after some time a slow vermicular-like contraction, which was perceptible to the touch of the finger, and was more remarkable when the positive pole was directed to the spine and the negative to the cervix, than when both poles were directly applied to the substance of the uterus. Besides, he found that the electric current, directed longitudinally through the uterus, that is, from fundus to cervix, promotes powerful and general uterine contraction, whereas a current passed transversely through the organ excites partial contractions only in the direction of the current. Dr. Mackenzie mentions that the contraction of the contractile fibres of the uterus caused by galvanism differs widely from that of the other involuntary muscles when acted upon by electricity; but such is not the case, as the lower third of the œsophagus, the cœcum, the gall-bladder, and other involuntary muscles respond equally slowly to the galvanic stimulus as the uterus.

The contractility of the *blood-vessels* is proportionate

* Medico-Chirurgical Transactions for 1859, p. 160.

to the fibre-cells they contain. It has been affirmed by Vassali, Giulio, and Rossi that the aorta of man contracts when galvanized; but neither Nysten nor Kölliker have been able to perceive such contractions. The absence of contractility in the aorta is readily to be understood, if we take in account that the aorta consists almost entirely of elastic fibres, and contains only very few contractile fibre-cells, which, even when excited by galvanism, are not capable of counterbalancing the elastic force which continually tends to keep the aorta open. The contractile fibre-cells are much more abundant in the smaller arteries of man, and consequently these are seen to contract energetically when galvanized. In horses, cows, and sheep, the aorta contains more fibre-cells than that of man; it is therefore probable, that, were the aorta galvanized in those animals, contractions would be produced. The small arteries of man are much constricted when galvanized; these constrictions are not observable immediately after the commencement of the current, but only after the action of the electricity has been kept up a certain time. And if galvanism is discontinued, the constrictions may still increase for a short time, and then slowly disappear.

IX. *Action of the electric current upon the heart.*

The phenomena produced by the galvanization of the heart differ according to the parts of the heart acted upon. If the ventricle and the atrium of a frog's heart, which is still actively pulsating, are galvanized, the heart becomes constricted, and its movements may cease altoge-

ther; but if the electrodes are applied to the bulbus aortæ, the pulsations become much more powerful; they disappear entirely if an electric current is caused to act on the vena cava, but begin again after the cessation of the current. These differences are only to be understood by remembering that the heart has two sets of nerves, viz.:—branches of the sympathetic nerve and of the vagi. If the former are galvanized, the action of the heart is augmented, while by galvanization of the latter the pulsations are stopped. This fact was discovered by Professor Weber, of Leipzig; M. Claude Bernard has observed many other interesting phenomena after galvanization of the vagi.

If the vagi are galvanized without having been previously cut, the action of the heart as well as the respiratory movements are arrested, and the eyes protrude; from this it is obvious, that there is at the same time a centripetal and a centrifugal action of the vagi. If a section of the vagi be made in dogs, and the upper ends of the nerves be galvanized, the pupils are dilated, and the eyes protrude; if galvanism be then discontinued, the eyes are drawn backwards and the pupils constricted. By galvanization of the *upper ends* of the vagi no effect whatever is produced upon the action of the heart, and if the current be gentle, the respiratory movements also continue undisturbed; but if a strong current be used, the respiratory movements are stopped during inspiration; the blood in the carotid arteries becomes black, and a passive injection of the mucous membrane of the cavity of the

mouth is produced, the tongue appears brownish black, in consequence of the momentary asphyxia produced by galvanization of the upper ends of the vagi; but the arteries continue to beat. If galvanism be then discontinued, the respiratory movements begin again, and the velocity with which they succeed each other is even greater than before the galvanization was commenced. Besides, after galvanization of the upper ends of the vagi, sugar is found in the blood, in the cerebro-spinal liquid, and in the bile; the secretion of urine appears to be arrested, and a flow of saliva is observed: this saliva, however, is much more viscid than that observed to flow after the galvanization of the lingual nerve, or of the chorda tympani.

Galvanization of the *lower ends* of the vagi produces opposite effects: it does not stop the respiratory movements, as is done by galvanization of the upper ends; but it arrests the pulsations of the heart and the arteries.— Besides, it generally causes vomiting.

If after death the heart of an animal has ceased to act, and an induced current is applied to it, rhythmic contractions of the heart are again observed. These contractions are much more marked in the right than in the left ventricle. After death the left ventricle is generally firmly contracted, and insensible to the electric stimulus; the right ventricle, on the contrary, is almost always overloaded with blood, and contracts very powerfully when galvanized. In animals killed by chloroform, sometimes the left ventricle still continues to pulsate feebly, while the action of the right ventricle is entirely stopped,

in consequence of excessive distention with black blood. If in such instances the right ventricle is galvanized, its pulsations begin again and the dilatation becomes less. From this we may infer that galvanization of the right ventricle may be resorted to in cases of chloroform poisoning during surgical operations, after the usual remedies, especially artificial respiration, have failed.

But it is of paramount importance, that in such instances a gentle current should be used, as a strong current would, in all probability, totally annihilate the excitability of the heart. Baron Humboldt has performed interesting experiments with electricity on the heart of a carp which had been cut out of the body.* Immediately after that operation had been performed, there were 34 pulsations observed in a minute; the heart was then touched with a solution of kali sulphuratum, after which only nine pulsations took place. Five minutes after the heart had been cut out there were only three pulsations in a minute. Feeble discharges from a jar were now directed to the substance of the heart, when the pulsations again rose to 28 in a minute; a somewhat stronger discharge was then administered, and the pulsations again fell back to eight, a still stronger discharge entirely destroyed its contractility, and no stimulus was capable of inducing further pulsations.

X. *Action of the electric current upon the blood.*

The action of electricity on the blood is wholly chemi-

* Untersuchungen über die gereizte Muskel und Nervenfaser. Posen und Berlin, 1797. Vol. ii. p. 214.

cal, and it is, therefore, easy to understand that the continuous current will have more effect than frictional electricity, or the induced current. By using the continuous current we are able to coagulate blood which has been taken from an artery or a vein, or capillary vessels; and, also, while the blood is still circulating in the living body. If arterial blood is acted upon, a rather firm clot is formed, which adheres to the walls of the artery, and will stop the circulation. Clots may be produced in veins just as well as in arteries, but the clots formed of venous blood are less firm and more dark than clots of arterial blood. If a current of moderate intensity be used, the time required for the formation of clots is ten to fifteen minutes.

If the coagulation of the blood is induced by electricity, the clot is formed only at the positive pole, in consequence of the decomposition of the salts of the blood and the liberation of acid at the positive pole; at the same time, alkali is liberated at the negative pole, in the neighbourhood of which the blood is therefore rendered more fluid. If an electrode connected with the positive pole is placed into the artery of a living dog, the blood is soon coagulated; and no pain, or inflammation, or gangrene are produced; but if an electrode connected with the negative pole is thrust into the artery, the blood is rendered more fluid, and pain, inflammation, and gangrene may be the result. From this it is obvious that if we want to coagulate the blood by electricity in aneurism, the positive pole only should be directed to the aneurismal sac,

and the negative pole to any point of the skin which covers the tumour.

XI. *Action of the electric current upon the skin.*

Sparks taken from the common electrical machine produce a sharp sensation in, and a peculiar eruption on, the skin, viz. a small circumscribed wheal which resembles lichen urticatus, and is surrounded by a little inflammatory blush. The action of the continuous current upon the skin differs, according to the intensity of the current, to the resistance offered to its passage, and to the length of time during which the action of the current is kept up. Thus there is only a trifling action if the skin be dry; it is much more remarkable if the epidermis be moistened previous to the application of the electrodes, and still more so if the epidermis be totally removed by blisters. This was first pointed out by Baron Humboldt, in 1795. He had two blisters, each of the size of a crown, applied to the neighbourhood of the two shoulder-blades, above the trapezius and deltoid muscles. By cutting the blisters open, a serous uncoloured liquid was seen to flow out. He then had the excoriated spots covered with a silver plate, and as soon as a zinc plate was connected with it, a liquid was seen to flow which no longer appeared uncoloured, but was of a reddish hue, and which produced considerable inflammation on those parts of the skin which were touched by it, at the same time a strong burning pain was perceived. Baron Humboldt relates that for several hours after this experiment

he looked like a soldier who had been flogged. If the action of a feeble continuous current be kept up for some hours, destruction of the skin and the subjacent structures will be produced; if a powerful pile be used, the destruction will take place very rapidly; this effect is always more striking at the zinc pole of a single pair, as by the action of the current the saline fluids effused on the surfaces of the blisters are decomposed, sodium being liberated at the silver surfaces, and chlorine being evolved at the zinc plate, thus forming chloride of zinc, the escharotic action of which produces ulceration of the tissues. On the silver plate sodium is set free, which by oxidation rapidly becomes soda. Proceeding from these facts Dr. Golding Bird has recommended the action of the zinc pole for establishing an electric moxa in cases where we may wish to induce a persistent discharge from some part of the body; the opposite action of the silver plate has been used by Mr. Spencer Wells to favour a rapid healing of torpid ulcers.

If an induced current of some intensity be applied to the skin, an erythema is produced, especially if the skin be quite dry; and if the intensity of the current is very great, circumscribed wheals are produced, the same as by frictional electricity. This is especially remarkable if the current be applied by means of fine metallic wires. The erythema is more easily produced in women and in persons generally where the skin is delicate; besides, it is more remarkable at the negative than at the positive pole. An increase of temperature in the skin is also produced, as more blood is attracted to it, in a given space of time.

The contractile fibre-cells of the skin are also excited by the induced current, and therefore cutis anserina is produced;* the contractions of the fibre-cells are most remarkable if the tunica dartos and the nipple are galvanized; the latter soon becomes erect, and remains so for a long time after the cessation of the current. The fibre-cells of the hair-roots can also be excited by galvanism; and if a current be applied to such parts of the skin as are covered with hair, the latter becomes more or less erect.

XII. *Action of the electric current upon the bones.*

If an induced current is applied by means of moistened conductors, to bones which lie immediately beneath the skin, a very strong pain of a peculiar character is produced, in consequence of the irritation of the sentient nerves of the periosteum. The pain is especially strong on the forehead and on the tibia.

It is probable that by applying electricity directly to the periosteum and the bones, a greater quantity of blood may be attracted to the parts acted upon. In 1853 there was a case of un-united fracture of the leg at the York County Hospital, under the care of Mr. Holl; the fragments were very movable, and the fracture had existed for more than a year. Mr. Holl introduced a needle from each side of the limb into the interspace between the bones, and then passed a continuous galvanic current

* Kölliker has caused a cutis anserina on a piece of skin which had been cut from the thigh of a culprit who had been executed a short time before.

through. The operation was repeated every day for about a fortnight, and a cure ultimately resulted.* There is no specific action of electricity upon the bones, but in the case just related the electric current acted merely as an excitant.

* Medical Times and Gazette, Nov. 12, 1853.

CHAPTER III.

MEDICAL ELECTRIC APPARATUS AND ITS APPLICATION.

In this chapter I intend describing the electrical machines which may be used for therapeutical purposes, and the methods in which the different forms of electricity have been, and are to be, medically applied. I shall speak at first of the common *Electrization*, or of the medical application of frictional electricity; I shall then consider *Galvanization*, or the application of the continuous current of galvanic electricity; and at last *Faradization*, or the method of localized application of induction currents.*

I. *Electrization.*

The first who applied static or frictional electricity for medical purposes, was a German physician of the name of Kratzenstein, who has recorded a case of paralysis of a finger cured by sparks drawn from the common electrical machine (1744.) In 1748 M. Jallabert published a trea-

* This term has been first proposed by Dr. Duchenne, in order to connect the name of Faraday, who discovered the important phenomena of induction, with this new method of applying electricity.

tise on the effects of electricity upon the living body, and stated that the phenomena generally observed after the application of electricity were the following: acceleration of the pulse, increase of heat, and involuntary contractions produced in paralyzed muscles. In 1772, the Abbé Sans published a treatise on electricity, in which he reports eight cases of paralysis either cured or considerably ameliorated by electricity.

In 1778, M. Mauduit gave a highly favourable account on the curative effects of electricity before the Société Royale de Médecine, at Paris; and it was chiefly in consequence of this report that the application of electricity to various diseases became for some time fashionable in the medical world. According to Mauduit electricity is an exciting remedy; it increases the vital powers, swells those parts of the body which are touched by it; and excites perspiration and even salivation, which frequently become very abundant if the electricity employed is of high tension. By applying electricity to patients, obstinate pains are relieved, the normal heat is restored in parts which have been cold for years; patients suffering from costiveness experience abundant evacuations; muscular atrophy, œdema, paralysis are cured, and tranquillity and sleep are readily induced by electricity. The pulse at the wrist is strengthened by positive electricity, but reduced in frequency by negative electricity.

A few years later Cavallo collected a number of observations, in his essay on the theory and practice of medical electricity. He recommended the use of the electri-

cal machine in paralysis, deficiency of vision, deafness, chorea, epilepsy, and for rescuing persons from apparent death. In 1802, M. Sigaud de la Fond published a treatise on medical electricity, in which he most elaborately described the different methods which he thinks ought to be employed in the use of electricity. There are, according to him, not less than seven different methods of applying frictional electricity, viz. as an electric bath, by drawing sparks, by irroration, friction, insufflation, exhaustion, and commotion. If we were to believe M. Sigaud de la Fond, there is scarcely a disease known in pathology, that could not be cured by electricity.

After the discovery of the voltaic pile (1800,) and especially after that of electricity by induction (1831,) the medical use of frictional electricity has been more or less abandoned; and it is only in the electricity room of Guy's Hospital, under the superintendence of Doctors Golding Bird and Gull, that therapeutical experiments on a large scale have been undertaken with it. Quite recently static electricity has again found a stanch advocate in Dr. Clemens, of Frankfort, who has undertaken the irksome task of curing nearly all diseases which exist by means of electricity; but generally speaking, frictional electricity may be said to have disappeared from medical practice. This is especially due to the circumstance that a clumsy apparatus is required for its use; that the dose of electricity to be administered cannot be exactly regulated, and that by frictional electricity we are obliged to act indiscriminately upon the different tissues, without

being able to localize the stimulus in those parts which require it. The principal methods of applying static electricity, which are even at the present time now and then used, are the electric bath, electrization by sparks and shocks from the Leyden jar.

As to the form of the machine, it matters little whether a glass cylinder or a glass plate is used. As a curious fact, I may mention that in the last century Signor Pinati, of Venice, used in his machines glass cylinders filled with Peruvian balsam, and various other medicines; and Dr. Giuseppe Bruni has even recorded a case, in which he employed a glass cylinder filled with purgative substances, and the patient, after having been electrified, is said to have experienced the same effects as if he had swallowed the drug.

1. *The Electric Bath.*

The electro-positive bath is said to increase the vital forces, the electro-negative bath to diminish them. If an *electro-positive* bath is to be given, we must collect the electricity accumulated upon the glass plate, and take care that the negative electricity, which the cushions or rubbers acquire by friction, be lost in proportion as it is liberated. Therefore the cushions, between which the plate or cylinder of glass is turned, must communicate with the ground by means of a metallic chain connected with the cushions. The machine being in action, the patient is placed upon an insulating stool and takes hold of the prime conductor of the electrical machine. Now the

whole surface of the body of the patient becomes charged with positive electricity, while the air surrounding it is rendered negative. If the electric bath be given in a dark room, luminous appearances are produced by the escape of electricity into the air, especially about the hair and the eye-lashes. It is said that during the discharge, heat is evolved, the circulation is quickened, and the secretions, especially perspiration, become more active; but it is very doubtful if these be constant physiological effects produced by the electric bath: probably they are merely caused by the excited imagination of the patient. The electric bath has been especially recommended in certain affections in which the functions of the skin and of the mucous membranes are deficient; and the patient ought to sit in it for about three hours a day.

If an *electro-negative* bath is to be given, we must collect the negative electricity acquired by the cushions, and take care that the positive electricity accumulated upon the glass plate be lost in proportion as it is liberated. The cushions must therefore be insulated by means of glass supports, and the conductor upon which positive electricity is liberated, must be made to communicate with the ground by means of a metal chain. The electro-negative bath is said to have a weakening effect, viz. to reduce the natural electricity of the patient, so that the body is left without its natural stimulus; it, therefore, is said to act like blood-letting, and the pulse at the wrist is thereby reduced in frequency. It has been recommended for erysipelas and chronic inflammations of every

kind; more especially for head-ache and different forms of neuralgia; but it appears extremely doubtful if there really be any constant physiological effect in the electro-negative bath.

Electrization by Sparks.

If a patient is sitting in an electric bath, and the hand of the operator be brought sufficiently near to the patient's body, it becomes negative; and the negative electricity combines with the positive electricity of the patient's body, whereby a vivid flash of light is produced, together with a peculiar snapping noise, which forms the electric spark. Sparks may also be drawn from the body of a patient by approaching metallic conductors to any part of the body. These sparks produce a sharp pricking, or pungent sensation, at the points touched; and if the proceeding be continued for a certain time, the skin becomes reddened, and white circumscribed wheals may be produced. This eruption is more considerable in persons with a delicate skin; the time necessary for its production varies in different persons from five to ten minutes; it generally disappears within an hour from its production. In the electricity room of Guy's Hospital sparks are generally taken from the spine, in the following way: a brass ball, furnished with a wire or chain, in connection with the ground, is passed upwards and downwards in the direction of the spine at a distance of about an inch from the surface; the machine being put in action, the patient, sitting on an insulating stool, becomes charged with elec-

tricity, and sparks pass to the brass ball, and thence escape through the wire or chain to the ground; in this manner a rapid succession of sparks can be obtained, which act like instantaneous electric currents. Cavallo has recommended drawing electric sparks through flannel; the patient sits on the insulating stool, as usual, and takes hold of the prime conductor of the machine; a piece of flannel is placed over the part which is to be electrified, and the machine being put in action, the knob of an insulated conductor is placed in close contact with the flannel, and is then moved steadily down the part affected, so as to draw a very large number of small sparks in the direction of the ramifications of the nerves. Sparks, if they succeed each other rapidly, may also produce slight vibrations in muscles which are close under the skin. Electrization by sparks has been much used for paralysis, chorea, and other affections of the nervous system; the effect obtained by it is in direct proportion to the power of the machine, and the more or less rapid succession of the sparks.

3. *The Leyden Jar.*

The Leyden jar yields a rather large quantity of electricity accumulated under a small surface. To charge the jar, it is held in the hand by its outer coating, and the knob which communicates with the inner coating is presented to the conductor of the electrical machine while in action. Thus the inner coating of the jar receives positive electricity from the machine, while nega-

tive electricity is accumulated on the outer coating, and if a communication be established between the two coatings, neutralization takes place between the two contrary electricities. If the jar is discharged through the human body, a violent, sudden, and painful sensation, the *electric shock*, is perceived. The force of the shock is proportional to the area of the metallic coating and to the intensity with which the jar is charged; a large jar will give a more powerful shock than a small one, providing both are charged to the same intensity. The shock from a Leyden jar may be transmitted through a number of persons forming a chain; the first taking hold of the jar by its outer coating, the last touching it by the knob. If numbers of jars are combined to form batteries and discharged through the human body, the concussion may be so strong that the whole body is affected by it as if struck by lightning. If the discharge takes place through the arms, the shock is mostly felt in the wrists, elbows, and across the chest.

If we want to apply the Leyden jar to a peculiar part of the body, a conductor with two branches is generally used, which communicates by one of its branches with the inner coating of the jar, while the other branch is approached to the surface of the part which we intend operating upon; the outer coating of the jar is then held to the opposite surface of the part; whereby a spark is produced, and the neutralization of the two contrary electricities takes place through the parts between the conductor and the outer coating of the jar. In Guy's Hos-

pital shocks from the Leyden jar are especially employed in the treatment of amenorrhœa; in such cases the jar is discharged through the pelvis.

In my opinion, static electricity can be entirely dispensed with in medical practice, as it presents many inconveniences which are not compensated for by the advantages which may be derived from it. Dynamic electricity, on the contrary, appears to be the true medical electricity, and is now almost exclusively used for therapeutical purposes.

II. *Galvanization.*

Galvanism was discovered in 1786, and its medical application soon afterwards recommended by Drs. Behrend and Creve for distinguishing real death from apparent death or trance. Soemmering proposed that in such instances the galvanic current ought to be applied to the neighbourhood of the phrenic nerve. Valli succeeded in revivifying, by the galvanic shock, frogs which had been all but suffocated in vessels filled with hydrogen, and fowls which had been all but drowned. Hufeland, Pfaff, Reil, Baron Humboldt, and other German Philosophers and Physicians strongly recommended the use of galvanism for the cure of disease, without, however, having tried it themselves in medical practice.

The first therapeutical experiments on patients were made with the current of a single pair, at the University College Hospital, at Jena, under the supervision of Prof. Loder, without success. But after the discovery of the

voltaic pile (1800,) experiments of this kind were again commenced by Drs. Bischoff and Liechtenstien, who have recorded the cure of two cases of amaurosis and the amelioration of a case of hemiplegia. The first systematical treatise published on the remedial powers of galvanism is from the pen of Dr. Grapengiesser, of Berlin (1801.) He recommended the use of galvanism in deficiency of vision and amaurosis; in deafness, hemiplegia after the cessation of the pressure on the brain; in other paralytic conditions, aphonia, tumor albus, rheumatism, and sciatica. In palsies he applied the direct current, and placed the positive pole on the trunk of the nerve, and the negative pole lower down; or he used basins filled with water, in which the poles, and the feet or hands of the patient, were immersed. In all other diseases he applied galvanism, after having vesicated the skin by means of blisters, in order to diminish the resistance to the passage of the current. A few years later, Drs. Jacobi and Augustin published treatises on galvanism as a remedial agent, and recommended the moistening those points of the skin to which the electrodes were to be applied, in order to diminish the resistance to the passage of the current. The most celebrated of the early treatises on medical galvanism is by Galvani's pupil, Aldini, of Bologna.* Very curious are his observations relating to the treatment of insanity by galvanism. He remarked that, when he applied the galvanic current to himself, in the neighbourhood of his ears, he became much excited, and con-

* Essai théorique et expérimental sur le Galvanisme. Bologne, 1804.

tinued sleepless for several days. He, therefore, thought it worth while to try galvanism on insane patients, who required excitement; and he relates two cases of melancholy which were actually cured by the application of galvanism. Dr. Remak thinks that in these cases there was probably a chronic inflammation of the meninges, or of the surface of the brain, as, in his opinion, a continuous current, sent through the brain of patients suffering from such diseases, may effect a cure!

As great as had been the enthusiasm for the newly-discovered remedial agent, was the disappointment which necessarily followed after the unbounded expectations which had been entertained, had not been realized. In most of the cases treated by galvanism, no success was observed; besides which, the current furnished by the voltaic pile proved to be very inconstant, and the use of the pile troublesome and expensive, and by the application of two strong currents, even accidents of a serious character were produced. The confidence in the curative powers of galvanism was, therefore, totally shaken, and the voltaic pile was ranged together with talismans, amulets, and animal magnetism among the pharmacopœia of quackery.

In 1825, a new era in the application of galvanism was inaugurated by Sarlandière, who proposed applying the voltaic current by means of acupuncture needles, whereby the current was allowed to penetrate more deeply into the organs, and at the same time was limited to those parts which required the galvanic stimulus; and Magendie suc-

ceeded in effecting remarkable cures of paralysis, amaurosis, and neuralgia by means of this proceeding. From that time the attention of medical men became again directed to galvanism. Guérard and Pravaz proposed curing aneurisms by galvano-puncture; it was first tried on living man by Liston, and the first success was obtained in a popliteal aneurism by M. Pétrequin. Wires rendered incandescent by voltaic electricity were employed for cauterization by Steinheil, Middeldorpff, and Amussat. Prévost and Dumas, Bonnet, Melicher, and Bence Jones, succeeded in decomposing calculi of the human bladder by means of the continuous current, and Mr. Spencer Wells applied the current of a single pair to promote the growth of healthy granulations and the cicatrization of ulcers. The continuous current as applied to diseases of the nervous system had again gone out of use, being replaced by the induction currents, when Dr. Remak, of Berlin, endeavoured once more to prove it a first-class remedy for these complaints.

The question, viz.: which apparatus should be used if we wish to employ the continuous current, is of great importance. The ordinary voltaic pile has entirely disappeared from medical practice, as it is a troublesome apparatus, and the current furnished by it is inconstant. Recently, in its stead, Cruikshanck's battery has been much used: this battery is much more easily manipulated, but its current is equally inconstant as that of the voltaic pile. Cruikshanck's battery consists of plates of copper and zinc which are arranged in wooden troughs.

One trough generally contains fifty pairs, so that by two troughs a rather strong current is furnished. To excite the battery, water, or salt water, or acidulated water, is used: if distilled water be employed the chemical action is very weak; but if acidulated water be used, the intensity of the chemical action is much increased. I have explained in the first chapter the reason why the ordinary voltaic pile and all batteries similar to it furnish an inconstant current.

The most powerful and constant batteries are those constructed by Daniell, Grove, and Bunsen, one of which should be used, whenever constant physiological, or chemical, or calorific effects are required. Daniell's battery is especially adapted for medical purposes, because nitric acid is not required for exciting its action; as is the case in the batteries of Grove and Bunsen.

The continuous current of one of these batteries may be applied in the following way: for sending the current right through the body, the feet or the hands of the patient should be immersed in two vessels filled with water or salt-water, and connected separately with the poles of the battery. To localize the continuous current in certain parts of the body, insulated directors or excitors are employed, which are separately connected at one extremity with the poles of the battery, and at the other extremity covered with moistened sponge or flannel.

To practise *Electro-puncture*,* two fine platinum needles are connected with the poles of the battery and in-

* Mémoires sur l'électro-puncture par M. Sarlandière. Paris, 1825.

troduced into the tissue which we intend to act upon. Then the continuous current may either be sent through for a certain time without opening the circuit, as must be done if we intend producing the coagulation of the blood in an aneurismal sac; or the circuit may be alternately made and broken, as was recommended by Magendie for the treatment of neuralgia and amaurosis.

If we wish to use the *galvanic cautery*, we had best employ the instrument devised by Professor Middeldorpff, of Breslau.* His "galvanic cautery" consists of a wooden handle which can be separated in two lateral halves, and is traversed in its whole length by two gilt copper wires, by which the current is conveyed. One of these wires is divided in two halves; if these two halves be separated from each other, there is no action of the current; but by uniting them, which is easily done by turning a screw, the circuit is established. At their posterior extremities, the wires are connected with the poles of the battery; while at the anterior end a platinum wire is inserted, which is immediately rendered incandescent if the circuit is established. To this platinum wire different forms may be given, according to the shape of the tissues upon which we desire to act. This instrument while cold may, therefore, be introduced into a cavity: when it is in its right place, the circuit is made by uniting the two parts of one of the conducting wires; and if the cauterization is to be discontinued, the circuit is broken

* Die Galvanokaustik. Breslau, 1854.

by separating the two parts of that wire; after which the instrument may be removed without injury to the parts.

Besides, Professor Middeldorpff has constructed a galvanic porte-ligature and a galvanic seton; the latter consists of platinum wires of different diameter, which are conducted by means of needles through such tissues as are to be subjected to the galvanic cautery.

If we intend concentrating the heat evolved by the galvanic current upon a considerable surface, an instrument invented by Mr. Ellis* will prove useful. The body of this instrument is formed by a silver catheter, straightened out, with the end cut off. At the upper end the catheter is slit open and broached, so as to form a socket for the porcelain cauterizer. Two conducting wires connected with the poles of a battery are placed within the catheter; their free extremities are connected with a piece of platinum wire, which is coiled around the porcelain in order to render this incandescent. The porcelain must be heated to whiteness. Mr. Ellis has employed this instrument in duration of the os and cervix uteri, in ulceration of the os, prolapsus uteri, and prolapsus of the anterior wall of the vagina. In cases of this kind, a glass speculum coated with gum-elastic is first introduced into the vagina; the os is then cleansed with a piece of wool, the cautery heated, and quenched in the diseased tissue; the duration of the application and the depth of its introduction depending upon the effect required. Eschars are easily produced, and the cervix uteri is often

* The Lancet, 1835. Vol. ii. p. 502.

seen to contract under the application of the cautery. Four pairs of Grove's battery are sufficient to render platinum wires incandescent, but it is essential that the plates of the battery should possess a large surface, in order to liberate a large quantity of electricity.

I now proceed to mention certain apparatuses by which a continuous current of galvanic electricity is produced, and which are directly applied to the body without the intervention of conductors or electrodes. One of these apparatuses is the *galvanic poultice of M. Recamier*, which forms a little voltaic pile regularly arranged. It consists of pieces of cotton-wool, which contain ribands or minute particles of zinc and copper, each pair being separated by flannel. The wool is placed in a bag, one surface of which is made of an air-tight and impermeable substance (gutta-percha,) the other of cotton. The permeable surface of the bag is applied to the skin and fixed by a roller; the impermeable surface retaining the perspiration, which soon accumulates in a liquid state and excites the action of the pile. More active effects are felt if the flannel is wetted with vinegar. If one of these poultices be bound tightly to the skin, a sensation of warmth is felt; if two of them are applied, pricking is felt, and the skin becomes red. This apparatus may be worn day and night, and is said to have been used with benefit in cases of amenorrhœa, rheumatism, etc.

Pulvermacher's electro-galvanic chain batteries consist of a more or less considerable number of pairs forming a little voltaic pile; these pairs have a very small volume,

and the apparatus consequently furnishes a comparatively small quantity of electricity, but which possesses a high tension. Each pair of the battery consists of a piece of wood, round which are coiled a zinc wire and a brass wire; each wire terminates in a ring, by which it is connected with the heterogeneous wire of the next link, that is, the zinc with the copper, and the copper with the zinc. At one end of the chain the zinc wire is free, forming the positive pole; at the other end the brass wire is free, forming the negative pole. If these chains are immersed in vinegar, the wood is impregnated with fluid, whereby the action of the battery is excited, the wood serving as a moist conductor. Caution is necessary in applying the chains to the face in cases of neuralgia, as they have a very remarkable action on the retina. Besides, if these chains are worn for a certain length of time, the position of the poles should be changed every now and then, lest a cauterizing effect should be produced. Pulvermacher's chains have been usefully applied to the treatment of certain nervous disorders, but we must bear in mind that the current generated by them is very inconstant. I should not recommend the use of the chains in amaurosis, because the electricity furnished by them is of high tension, and consequently the optic nerve is fatigued by it; it is much more rational to employ in such cases a few large plates of Daniell's or Grove's batteries, which furnish a much more considerable quantity of electricity, and which is of lower tension.

Messrs. Breton frères have also constructed some gal-

vanic apparatuses for direct application to the skin. The *electric girdle of Breton* consists of zinc and copper plates, which are separated from each other by a moist mastic; it furnishes very little electricity. The *electric mixture of Breton* consists of two pastes, one of which contains a powder of zinc, the other a powder of copper, mixed with saw-dust and chloride of calcium in order to preserve the humidity.

Dr. Golding Bird has recommended the local application of a single galvanic pair, to produce the effects of a moxa. He thinks the *electric moxa* eminently suited whenever a persistent discharge from some part of the body is required; it is employed in the following way:—The cuticle is raised on two points of the body by means of blisters, one being placed a few inches below the other. A piece of zinc foil is then applied to the one from which a permanent discharge is required; a piece of silver to the other; both metals are connected by a copper wire, and covered with a plaster. If the zinc plate be raised a few hours after the circuit has been established, the surface of the skin looks whitish, as if nitrate of silver had been applied to it. In 48 hours an eschar is produced, which begins to separate four or five days afterwards. The eschar is produced by the chemical action of the continuous current, in consequence of which the fluid effused on the surface of the blister is decomposed, sodium being set free at the silver plate, where by oxidation it rapidly becomes soda; and chlorine being evolved at the zinc plate, where consequently chloride of zinc is formed. The chloride of zinc,

originated by electro-chemical action, produces the sore, which will freely discharge pus if a common poultice be applied to it. While this process is going on, the patient hardly ever complains of pain, probably because the caustic acts in infinitely small portions upon the skin, in proportion as it is liberated.

III. *Faradization.*

The discovery of induction currents (1831) caused a new era in the medical application of electricity. The first induction apparatus suited for medical use was constructed by M. Pixii; the first physician who employed induction currents for therapeutical purposes was Dr. Neef, of Francfort. Induction machines for medical use, both volta-electric and magneto-electric, have afterwards been constructed by Messrs. Saxton, Clarke, Keil, Stöhrer, Breton, Du Bois Reymond, Horne and Thornthwaite, Duchenne, Legendre and Morin, Bernard, Baierlacher, and others. The choice of a good induction machine is, of course, a matter of the greatest importance, and it is a fact, that until of late there have not been any apparatuses constructed in which all the conditions necessary for therapeutical application were united; as in most of them only the current induced in the second wire could be collected, and the regulation of the intensity of the current, as well as the greater or less rapidity of the intermittences, could not be well effected. I shall, therefore, now mention the conditions necessary for an induction apparatus suited to the treatment of disease, and state at once that

any induction machines possessing the under-mentioned qualities may be usefully applied in medical practice.

1. *The first point in question is whether the apparatus employed should be a volta-electric or a magneto-electric one.* Both of them have their panegyrists and adversaries.

The alleged inconveniences of volta-electric apparatuses, in which the current is induced by a single galvanic pair, are,—that they are expensive; that troublesome manipulations, involving loss of time, necessarily precede and follow the use of the machine, which is not ready to act at a moment's notice, as the battery requires charging and afterwards discharging; that acids are necessary to induce the current, whereby not only the battery, but also the bobbin of induction, are after a certain time spoiled; while, on the other hand, rotation machines are economical, always ready to act, and acids are not required in their use. But in my opinion the trifling loss of time incurred in charging and discharging the battery is scarcely worth consideration, and by few simple precautions all the destructive effects of the acids may be avoided, excepting the spoiling of the battery, which now and then requires a new piece of amalgamated zinc, which can be easily procured. The inconveniences connected with the use of magneto-electric machines have generally been overlooked; but it is well to state, that these machines frequently get out of order; that the fixed horseshoe magnet becomes in time demagnetized and requires re-magnetizing; that, while with a self-acting voltaic ap-

paratus the electrician can operate for several hours successively without assistance, when the magneto-electric apparatus is used an assistant is required to turn the handle connected with the endless chain of the apparatus, which puts in rotation the soft iron armature. This inconvenience, which is especially felt whenever prolonged applications are necessary, may, it is true, be avoided by the substitution of clock-work; but by this the rapidity of the intermittences cannot be so easily regulated. Besides, voltaic apparatuses furnish a much larger quantity of electricity than magneto-electric machines, a circumstance decidedly in favour of the former. However this may be, it is erroneous to suppose that the current induced by voltaic electricity and that induced by a permanent magnet of steel possess exactly the same physiological and therapeutical properties. Such is not the case, and the reason will be readily understood if we consider that the current induced by voltaic electricity rises at once from zero to its maximum, and then as quickly falls back to zero; while the variations in the density of the magneto-electric current are by no means so sudden. The magneto-electric current begins when the soft iron armature is withdrawn from the pole of the permanent magnet, it reaches its maximum when the armature is between the two poles, and is finally reduced to zero, if the armature arrives at the opposite poles of the magnet. This is the reason why the volta-electric current acts more on the motor nerves and muscles and the sentient nerves, and the magneto-electric current more on the

retina; and, in all probability, this is also the reason why the magneto-electric current is more beneficial in the cure of rheumatic callosities than the volta-electric current. *It is, therefore, necessary that the electrician should possess both sorts of induction machines; the volta-electric for the treatment of paralysis and neuralgia, and the magneto-electric, if induction currents are employed in treating deficiency of vision, and for the absorption of rheumatic callosities.*

2. *Doses of electricity require to be exactly measured* to suit the different constitutions, age, or sex of the patient, just as remedies for internal application ought to be given by weight; therefore every apparatus fit for medical use must possess a regulator, by means of which the intensity of the current may be easily increased or diminished. The apparatus must be able to furnish currents of very high tension, or no effect would be produced in certain cases of muscular atrophy and anæsthesia, especially if electricity is to be applied on spots where the epidermis is very thick, as, for instance, on the palms of the hands and the soles of the feet; on the other hand, a very mild current is generally required for galvanizing the muscles of the face in paralysis of the portio dura, and for exciting the recurrent nerve in hysterical aphonia.

We have seen in the first chapter that the intensity of the currents induced by voltaic electricity depends upon three conditions, viz.: the intensity of the inducing current of the battery, the transverse section and the number of convolutions of the wires, and the quantity and the more or less insulated state of the soft iron in the

centre of the bobbin. Consequently a current will be very powerful if the battery be strongly charged; when the wire is long and fine, and the soft iron employed is in the form of a bundle of wires covered with a layer of varnish. It would be very inconvenient if we were obliged to vary all three conditions, especially the length of the wires composing the coil, whenever it was necessary to diminish the intensity of the current. Before the researches of Professor Dove on the influence of a closed envelope of brass or copper on the power of the electro-magnet were generally known, it was customary partially to withdraw the soft iron from the axis of the coil, whereby the intensity of the current was diminished in proportion as the iron was withdrawn. To render the current very feeble, it is, however, much more convenient to cover the soft iron with a closed cylinder of brass or copper. By this, the intensity of the current can be exactly regulated, as it is quite proportionate to the more or less covered state of the temporary electro-magnet. But, although the current is very feeble when the soft iron is entirely covered by the cylinder, in some cases it may still be too strong; it is, therefore, well to interpose an imperfect conductor into the circuit, whereby the resistance to the passage of the current is increased, and the current thereby further weakened. The instrument that best answers this purpose is a tube of glass, the ends of which are united with metal screws which fasten on the conducting wires of the apparatus. A metal rod can be moved in the tube, which should be filled with water as

a bad conductor. The further this metal rod be taken out of the glass tube, that is, the larger the layer of water to be traversed by the current, the more the power of the current is diminished, and at a certain point it will no longer be felt on the skin, but only occasion a slight pricking sensation, when applied to the conjunctiva, the Schneiderian membrane, or the tongue. The same instrument may serve to compare the intensity of different apparatuses of induction. Thus, the layer of water remaining the same, the current furnished by a feeble apparatus will not excite any sensation in the tongue, while the current of a very powerful apparatus may give rise to strong sensations.

Some induction machines are so extremely powerful, that the current furnished by them ought to pass through a very large layer of water, if it is to be employed for therapeutical purposes. The most powerful electro-magnetic apparatus that has been constructed is that known as Rhumkorff's coil, in which the second wire is three miles in length, and consequently the tension of the current induced in the second wire is exceedingly high; for this reason, Rhumkorff's apparatus is scarcely suited for medical purposes.

The intensity of the *magneto-electric* current depends upon the power of the fixed permanent horse-shoe magnet, the number of convolutions of the wires, the distance of the soft iron armature from the poles of the magnet, and the velocity with which the wheel is turned. A magneto-electric apparatus, even surpassing in power Rhumkorff's

coil, is that constructed by Mr. Henley. In this machine there are two permanent magnets, each of which is composed of thirty horse-shoe steel magnets two feet and a half long, and from four to five inches broad; the induction coils attached to these magnets contain about six miles of wire. The tension of the current circulating in this wire is so extremely high, that a single shock from it is sufficient to destroy life.

3. *A volta-electric apparatus fit for medical use must furnish two currents*, viz. the *primary current or extra-current*, induced by the action of the spirals of the thick wire upon themselves; and *the secondary current, or the current induced in the second wire*, which is long and fine. Duchenne has drawn considerable attention to the fact that there is a difference in the physiological action of the extra-current (called by him current of the first order) and of the current induced in the second wire (called by him current of the second order.) According to Duchenne, the current of the first order acts chiefly on the contractile power of the muscles, while the current of the second order acts chiefly on the sentient nerves; and on the retina when applied by means of moistened conductors to any point of the face or scalp animated by the trigeminal nerve. Duchenne has referred this difference of action to a special elective power in each of the currents, and is borne out in this supposition by M. Bouvier; but I am inclined to adopt the view first put forth by M. Becquerel,* viz. that the difference in the physiological effects

* Traité des applications de l'électricité, etc. Paris, 1857.

of the two currents is merely due to the difference that exists in their tension. Duchenne's observations are correct, but his explanations are unsatisfactory, as there is no other difference than that which naturally arises from the physical condition of the wires; a current circulating in a short and thick wire possesses less tension than a current circulating in a long and fine wire. Therefore, the extra-current will have a trifling effect on the skin, which offers a great resistance to the passage of an electric current, and more effect on the contractile power of the muscles, which, in consequence of the large amount of water they contain, are better conductors of electricity; while the current induced in the second wire, which possesses a high tension, will not only powerfully affect the muscles, but also the skin and retina. For the same reason a layer of water is more easily traversed by the current induced in the second wire, than by the extra-current. Messrs. Breton frères have shown by a simple experiment, in which the arrangement of the wires was modified, that the effect which has been attributed by Duchenne to the current induced in the second wire may be obtained from the extra-current, and vice versâ. It is, however, important that the same apparatus should furnish both currents, as in some instances a current of very low, and in others of very high, tension is required.

4. Another most important point in the construction of an induction apparatus is the *rheotome*, *cut-current*, or *contact-breaker*, an instrument by which the opening and closing of the circuit is produced, and the use of which is

evident, since induction currents exist only on making and breaking the circuit, and not while it remains closed. The rheotomes mostly used are the toothed wheel, the mercury rheotome, and the trembler.

a. Toothed Wheel.

The axis of the toothed wheel is connected with one pole of the battery, while the other is placed in contact with an elastic plate, which rests against the teeth of the wheel. As soon as a rotatory movement is caused in the wheel, by means of a handle, the elastic plate leaps from one tooth to another, and each leap produces a rupture of the circuit, which is immediately closed again; so that, if the motion of the wheel is continued, a succession of interrupted currents is caused, which is slow or rapid according to the velocity with which the handle is turned. However ingenious this instrument may be, it presents the inconvenience of not being self-acting, but requires an assistant to put it in motion.

b. Mercury Rheotome.

This instrument consists of two vessels, filled with mercury, each of which is insulated, of two needles, and a rod. The needles are parallel with each other, and fixed transversely to the rod, which can be moved more or less rapidly by the hand or clock-work. The circuit is closed when the needles are plunged in the two vessels, and opened if the contact between the needles and the mercury is broken. At the moment the needles emerge from the

mercury, a spark is produced, by which the mercury is burnt; its surface is, therefore, covered with a black powder of suboxide of mercury, which prevents a perfect contact between the needles and the liquid metal. It is obvious that a rheotome, which is rapidly spoilt by the action of the current, especially if this be powerful, is devoid of practical importance.

c. Trembler.

In my opinion the trembler, originally invented by Neef, of Francfort, is the best of all rheotomes hitherto constructed, as it is self-acting and not easily spoilt: it allows of extremely rapid and very slow interruptions of the current, besides which, it notably increases the physiological effect of the current. The trembler consists of a small stem of soft iron placed horizontally beneath the bobbin of induction; this stem is fixed with one extremity to a metal piece outside of the bobbin, and is movable with the other extremity, which is put in motion by the temporary magnetism of the soft iron in the centre of the bobbin. A spring of platinum is soldered to the lower surface of the trembler, and rests upon a piece of copper, likewise covered with platinum. The metal stem communicates with one of the poles of the battery, and the piece of copper covered with platinum with the other pole. Hence it results that the circuit will be closed each time that the spring of platinum and the piece of copper covered with platinum are in contact with each other. Such being the arrangement the soft iron in the centre of the

bobbin is magnetized when the circuit is closed, and consequently attracts the movable extremity of the trembler. As soon as this has taken place the circuit is broken, as there is no longer a contact between the spring of platinum soldered to the inferior surface of the trembler, and the piece of copper covered with platinum. Therefore the central soft iron loses its magnetism, and the trembler immediately falls down by its own weight in its previous position. Thereby the circuit is closed again; the soft iron is again magnetized, the trembler is once more attracted to the electro-magnet, and the circuit interrupted again. Each time that the circuit is opened and closed, a spark passes between the two points of platinum; if the wires are very fine, these sparks are small; which causes the platinum to be very slowly oxidized. When the oxidation has taken place, the surface of the platinum must be cleaned; but the trembler can work for many years without being spoilt.

I have mentioned in the second chapter that the physiological effects of induction currents differ according to the rapidity with which they succeed each other; this circumstance has also an important bearing upon the therapeutical action of induction currents. A rapidly interrupted current acts much on the nutrition and tonicity of paralyzed muscles; and is very powerful in exciting the sentient nerves of the skin. It should, therefore, be employed in diseases where muscular nutrition is enfeebled, such as lead-palsy, Cruveilhier's atrophy, etc., and on the other hand, in anæsthesia of the sentient nerves. But it

will not do to employ a rapidly interrupted current, if we galvanize muscles paralyzed by an hemipletic attack; because irritation of the sentient nerves, which is always produced by rapid intermittances, must be carefully avoided in persons who have suffered from apoplexy. In such cases, therefore, and also if we galvanize delicate children or women, and for exciting the organs of sense, the current must be slowly interrupted.

From this it is easy to understand that an induction apparatus is worthless if we cannot change the more or less rapid succession of the currents. This may be easily done by working a screw, which withdraws the spring of platinum soldered to the trembler from the piece of copper covered with platinum; if the distance between the two is small, the induction currents succeed each other very rapidly; if it be increased, the succession of the currents is rendered slower. The differences in the slow or rapid succession of the induction currents are easily to be distinguished by the different sounds of the trembler.

So much for the apparatus. I will now proceed to give an account of the method of applying induction currents invented by Dr. Duchenne, and called by him Faradization.*

The method formerly used did not allow us to act on the diseased part without endangering the healthy organs and, in some instances, the whole nervous system. Dr. Duchenne, therefore, tried to solve the problem whether it were possible to localize electricity in the skin, without irritating the organs covered by it, or to penetrate the

* De l'électrisation localisée et de son application à la physiologie, la pathologie et la thérapeutique. Paris, 1855.

skin without irritating it, for concentrating electricity in a nerve or a muscle. The following facts are the basis of the system of localized electrization:—

When the skin and the electrodes are perfectly dry, and the epidermis very thick, as it is in many people whose professions expose them to the air and hard work, the two currents proceeding from an induction apparatus re-unite on the surface of the epidermis without penetrating the skin. They produce sparks and a special crepitation, but no physiological effect whatever. When dry excitors are put on such parts of the skin as are sensitive to electricity, the one subjected to the experiment feels a sensation of heat, which varies according to the intensity of the current. But when the skin and the electrodes are wet, neither sparks, nor crepitation, nor sensation of heat are caused, but different phenomena, according as one acts on a muscle, or on a nerve, or on the surface of a bone, are produced. In the last case a very strong pain of quite a peculiar character is caused, and it is not allowable to put wet electrodes on the surface of the bones. When the electrodes are placed on the surface of a muscle, the contraction of this muscle is produced, together with a sensation which is not peculiar to the skin, but always accompanies the electro-muscular contraction; as is the case, for instance, when one acts on a muscle which has been laid bare by a wound, and is no longer covered by the skin. Finally, when the excitors are put on the surface of a nerve, a contraction of all the muscles animated by this nerve is produced.

Duchenne has, therefore, distinguished two different methods of electrifying the muscles, viz. either by concentrating the electric stimulus in the nervous plexuses or branches, which communicate their excitation to the muscles animated by them ("indirect muscular Faradization,") or by directing the current to the muscular tissue itself ("direct muscular Faradization.") In both cases the skin and the excitors should be moistened. On the muscles of the trunks and most of the limbs wet sponges, lodged in metallic cylinders which are screwed on isolating handles, are applied. For limiting the electric force in the muscles of a smaller size, such as the muscles of the face, the interossei and lumbricales, small conical excitors, which are likewise screwed on isolating handles, are used. These excitors should be covered with wet leather, fingers of gloves, or moistened sponges.

Duchenne discovered that, if the electric current is directed to particular points of the skin the contractions of the muscles are much more easily produced than when the excitors are applied to the other points; these points he called points of election; but he did not state that they are the points of entrance of the motor nerves into the muscles. This was done by Dr. Remak,* who also contended that the degree of contraction of a muscle is exactly proportionate to the number of motor nerve-fibres embraced by the current at its point of application; and that there is no direct action of the electric current upon the muscular tissue, which is thrown in commotion only in con-

* Ueber methodische Elektrisirung gelähmter Muskeln. Berlin, 1856.

sequence of the excitation of the nerves. He, therefore, proposed calling Duchenne's indirect muscular Faradization "extra-muscular excitation;" and the direct muscular Faradization "intra-muscular excitation." This theory was more fully developed by Dr. Ziemssen,* who first clinically determined the precise localities of these points of election, and marked them upon the skin with nitrate of silver, and afterwards dissected the motor branches of the nerves in dead bodies, and minutely marked their points of entrance into the muscles; the results of these two series of experiments agreed with each other.

Drs. Remak and Ziemssen are both of opinion that there is no irritability proper of the muscular fibre, and, therefore, deny *a priori* the possibility of producing muscular contractions by direct electric excitation of the muscular tissue. I have demonstrated the existence of Hallerian irritability in the second chapter of this volume, and have shown that the molecular equilibrium of the muscles may be directly disturbed by the electric current, just as well as the molecular equilibrium of the motor nerves; and that contractions are observed as soon as the equilibrium of either motor nerves or muscles is disturbed. Besides, we have seen that the equilibrium of the motor nerves is far more easily disturbed by the electric current than that of the muscles; and that therefore, if we wish to cause direct muscular contractions by electricity, a current of greater intensity must be applied than is necessary if we produce contractions by excitation of the motor nerves. This is

* Die Elektricität in der Medicin. Berlin, 1857.

confirmed by the fact that contraction of a muscle may be produced if the electrodes are directed to such points of the belly of the muscle where motor filaments do not exist; but contractions are certainly more easily produced if the motor nerves are excited. In the majority of cases, however, the contraction produced by placing electrodes upon the belly of a muscle is composed of two elements, excitation of muscles and of nervous filaments.

Muscular Faradization requires exact knowledge of the anatomical position of the nerves. In the arm the electric stimulus can be limited to the median nerve on the inner and inferior third of the humerus; to the ulnar nerve on the interval between the olecranon and the internal condyle. The radial nerve is accessible to Faradization at the junction of the two upper thirds with the lower third of the humerus; the musculo-cutaneous may be reached in the axilla. On the thigh we may excite the crural nerve in the groin, outside of the femoral artery; the two popliteal nerves in the popliteal space. The sciatic nerve is accessible to Faradization on its origin in the pelvis through the posterior wall of the rectum, or near the tuberosity of the ischium.

The trunk of the facial nerve can be galvanized from the external opening of the ear and after it has emerged from the stylomastoid foramen, by placing one of the electrodes between the mastoid process and the condyloid process of the lower jaw. But neither of these ways should be resorted to in cases of paralysis of the portio dura; because if we place the electrode in the external opening

of the ear and apply a *mild* current, the deflection of the face produced is hardly perceptible, and if a *strong* current be used, the electric stimulus is inevitably conveyed to the superficial temporal or auriculo-temporal nerve, from the third branch of the trigeminal nerve; whereby a very strong pain is caused. It is, therefore, much better to galvanize the branches of the facial nerve where they emerge from the parotid gland or the individual muscles; which is especially to be recommended, because in paralysis of the portio dura scarcely ever all the facial muscles are paralyzed. These branches of the nerve are easily discovered, but it is well to add that there are in different persons slight variations in the situation of the motor points.

In the supra-clavicular region the excitors, placed immediately over the collar-bone, act on the brachial plexus. On the summit of the supra-clavicular triangle they are in connexion with the external branch of the spinal accessory nerve. The phrenic nerve is found on the anterior surface of the scalenus anticus.

Duchenne mentions that the muscles, like the nerves, do not all possess the same degree of excitability, and that therefore it is necessary to measure the electric dose for the different muscles; he states besides, that the electro-muscular sensibility, viz. the sensation excited by the electro-muscular contraction, also differs in different muscles. But, in my opinion, these differences arise merely from the more or less delicate state of the skin which covers the muscles.

I now proceed to an exposition of the method of electrifying the skin. Faradization of the skin is capable of exciting the sensibility of the nerves of the skin in the highest degree without in the least destroying the skin itself. If a current of high tension is applied to the skin by means of metallic wires, erythema is generally produced, which, however, very soon ceases; but vesication or gangrene, as is caused by applying a strong continuous current of galvanic electricity, is never produced by it. If we practise Faradization of the skin, the skin as well as the excitors must be dry; as, if the skin be moistened, the electric current follows those better conducting tissues which are close beneath the skin.

As the skin on different parts of the body has various degrees of sensibility there should be different processes of cutaneous Faradization. There are three principal processes which seem to fulfil all the conditions required.

The first process is Faradization by the *electric hand.* The patient takes in his hand one of the conducting wires which communicates with one of the poles of the apparatus; while a conducting wire, united with the other pole, is kept in the hand of the operator. After having dried the skin of the patient by means of a little rice-powder, the operator rapidly passes the back of his disengaged hand over the points to be excited. The electric hand produces, if a somewhat strong current be applied, a lively sensation on the face, but scarcely any sensation on the other parts of the body. Lively crepitation produced by the rapid passage of the hand over the skin is there the only appre-

ciable phenomenon. By increasing the intensity of the current, more violent sensations can be produced.

The second proceeding is Faradization by *solid metallic excitors*, which are screwed on isolating handles. The skin must be dry as before; but if the epidermis be very thick or hard, as is the case on the palms of the hands and the soles of the feet of many persons, the skin may be moistened a little, in order to diminish the resistance to the passage of electricity. When it is necessary to cause a strong effect on a certain point, the excitors are held some time in contact with the skin. The solid metallic excitors, though acting energetically on the skin of the face and of the trunk, are often insufficient for the palms of the hands and the soles of the fect, whatever may be the intensity of the current.

In such cases *metallic wires* are employed, in the shape of brushes lodged in metallic cylinders, which are screwed on isolating handles. The skin should be lightly beaten by these wires, but sometimes it may be necessary to leave them longer in contact with it.

I have already mentioned the exquisite sensibility of the skin of the face due to the ramifications of the fifth pair. A current of low tension exercises on it an effect which is by no means felt in the other parts of the body. Sensibility is much stronger near the middle line of the face, viz. in the eyelids, the nose, and the chin, than on the cheeks. On the forehead there is not so much sensibility as on the face, and very little on the scalp. It is more exquisite on the neck and on the trunk

than on the extremities; more in the cervical and lumbar region than on the other parts of the trunk; more on the inner and the interior surface of the extremities than on the external and posterior parts. The skin of the hands and of the soles of the feet can only be stimulated in a lively manner, if a current of high tension be applied by metallic wires. Faradization of the skin is useful in many cases of anæsthesia and neuralgia.

Finally, a few words upon Faradization of the internal organs. The drum of the ear may be galvanized in certain cases of nervous deafness. For this the meatus auditorius externus is to be filled with water; a metallic excitor is then held in the fluid, and the circuit is closed by placing the other moistened excitor on the nape of the neck. The excitability of the membrana tympani is great, and therefore the current applied ought not to be of very high tension. At the moment the circuit is closed those phenomena are produced which I have described at greater length in the second chapter (p. 104.)

In cases of loss of smell a very slight excitation of the general sensibility of the mucous membrane of the nose has often been sufficient to recall the lost or weakened sense of smell. A wet excitor having been placed on the nape of the neck, another excitor is conducted over all points of the Schneiderian membrane. For exciting the nerves of taste and the retina, it is more advisable to employ the continuous current, which exercises a much more remarkable influence on these organs than induction currents.

Faradization of the rectum and of the muscles of the anus has been used for the cure of involuntary stools and prolapsus of the rectum; as they are sometimes produced by paralysis of the sphincter and levator ani. Then a metallic excitor, the end of which has the form of an olive, being isolated by caoutchouc, is introduced into the rectum, and connected with one of the poles of an induction apparatus; another moistened excitor is applied near the anus. Previous to this operation the rectum must always be cleared from stercoral matters by enemata. The margin of the rectum is so very sensitive to the electric excitation, that a very feeble current applied to it excites an almost unbearable tenesmus. Therefore, if it is not necessary to act on the sphincter ani, the excitor must always be isolated.

Faradization of the bladder has proved useful in paralysis of that organ. To that end the double excitor of the bladder is used by Dr. Duchenne. It is composed of two flexible metallic wires, introduced into a sound of caoutchouc with a double channel, so that they are isolated. That end of the excitor which is to be placed in the bladder is so terminated that when being approached to each other, the wires present the form of an ordinary catheter. The excitor of the bladder having been closed and introduced, its wires are pressed forward one or two inches, whilst the caoutchouc sound remains in its place, so that the ends of the excitor are removed from each other. Care must be taken to empty the bladder before the operation, as, if the bladder were filled, the neutrali-

zation of the two contrary electricities would not be effected through the muscular tissue of the organ. The two wires are put in communication with the poles of the induction apparatus, and conducted over all points of the inner surface of the bladder.

The muscles of the pharynx can also be excited, and when paralyzed they may be beneficially affected. The excitor to be applied differs in no way from that which is used to stimulate the rectum. It is conducted on the pharynx, whilst the other wet excitor is placed on the nape of the neck. It is, however, necessary to avoid the excitation of the sides of the pharynx, as they are in relation with the glosso-pharyngeal, pneumogastric, and spinal accessory nerves; if they should be excited, Faradization would no longer be confined to the pharynx, but be extended to organs the stimulation of which would be dangerous.

Faradization of the larynx may be done in aphonia resulting from loss of power in the nerves and muscles of the larynx. The larynx can be excited directly or indirectly. The method for direct excitation is the following: The excitor of the pharynx is inserted in the pharynx as low down as the posterior and inferior part of the larynx. Another moistened excitor being placed outside, on the level of the crico-thyroid muscle, the former is conducted on the posterior surface of the larynx downwards and upwards, and vice versa. Indirect Faradization of the larynx is much easier. The excitor is directed on the sides of the inferior constrictor in order to

reach the inferior laryngeal nerve, which animates all the inner muscles of the larynx; and the circuit is closed by placing another moistened conductor on the nape of the neck.

Direct Faradization of the heart and the lungs, the stomach and the liver, is not possible; but stomach, lungs, and heart may be excited indirectly by Faradization of the vagi, accessible to the electric stimulus through the pharynx and œsophagus. Such operations seem, however, to be more dangerous than useful, so that a conscientious physician will seldom, if ever, consent to employ them.

The electric excitation of the diaphragm may easily be produced by Faradization of the phrenic nerve, which, taking its rise from the third, fourth, and fifth cervical pairs, proceeds downwards and inwards in front of the scalenus anticus, before it reaches the mediastinum and the diaphragm. The phrenic nerve may be easily excited, on the anterior surface of the scalenus anticus. Conductors with large surface, viz. sponges lodged in metallic cylinders, are held on the point alluded to, and the artificial respiration is instantly produced; the thorax is expanded and the air rushes into the lungs with considerable noise. By this means it is possible to maintain respiration even some time after death; and it may be easily conceived how important this agent may become in cases of asphyxia, whether it be produced by charcoal fumes, opium, chloroform, or by cholera. In all these cases the first indication is, to induce respiration, which is often to save life.

CHAPTER IV.

ELECTRICITY AS A MEANS OF DIAGNOSIS.

After galvanism had been used for some time in the treatment of paralytic diseases, it was observed that the muscles, being no longer under the influence of volition, were in some instances readily thrown in convulsion by the electric current, while in other cases no, or only very feeble, contractions were to be obtained. Hence it was thought possible to employ galvanism as a means of making or facilitating the diagnosis of certain obscure cases of paralysis.

Every means of diagnosis, when first pointed out as such, has been overrated, negligently employed, and consequently afterwards looked upon with distrust and contempt. Thus we are told in the Memoir of the late Dr. Hope, that some thirty years ago the prejudice against auscultation was very strong in this country, chiefly in consequence of several persons having brought the stethoscope from Paris, and having undertaken, without paying any attention to the general signs of the various cases, to form the diagnosis by the physical signs alone; they were constantly in error, and thus their undue pre-

tensions brought discredit on the whole system. The same has been the case with the microscope, the ophthalmoscope, and other valuable means of diagnosis; nor has galvanism been exempt from this fate. Observations on the irritability of the paralyzed muscles were negligently made, conclusions hastily drawn, and consequently the greatest confusion produced. For example; on the 6th of August, 1850, M. Martinet read a paper before the academy of medicine of Paris, in which he stated that the presence of electro-muscular contractility was the distinctive character of cerebral, hysterical, and rheumatic paralysis, while its absence was an indication of disease of the spinal cord. Now it is easy to prove that all these assertions are incorrect.

To Dr. Marshall Hall the merit is due of having first directed the attention of medical men to the value of electricity in the diagnosis of paralytic diseases. He contended in a paper on the condition of the muscular irritability in paralytic limbs,* that cerebral and spinal paralysis are in totally opposite conditions in reference to the irritability of the muscular fibre in the limbs severally affected. By cerebral paralysis he understands that which removes the influence of the brain,—paralysis of spontaneous or voluntary motion, such as is produced by disease of the brain itself, or by disease of the dorsal portion of the spinal cord (!) By spinal paralysis Dr. Hall understands that which removes the influence of the spinal cord. Now, he contends that in cerebral paralysis

* Medico-Chirurgical Transactions, 1839.

the paralytic limbs are always moved by an influence which is lower than that required to affect the healthy limb; or if both limbs are agitated it is uniformly the paralytic limb which is more shaken than the other. In spinal paralysis, on the contrary, the irritability of the muscles is diminished or even annihilated. Therefore he thought galvanism might afford a source of diagnosis between

1. Hemiplegia of the face, and
2. paralysis of the facial nerve.

3. Hemiplegia of the arm or leg, and
4. disease of the nerves of these limbs.

5. Disease of the spinal cord in the dorsal region, and
6. disease of the cauda equina in the lumbar region.

Dr. Hall concluded, that in cerebral paralysis the irritability of the muscular fibre becomes augmented from want of the application of the stimulus of volition, the brain being, in his opinion, the exhauster, through its acts of volition, of the muscular irritability; the spinal cord, on the contrary, being the special source of the power in the nerves of exciting muscular contractions, and of the irritability of the muscular fibre. In spinal paralysis, therefore, the irritability of the muscular fibre would be diminished, and at length become extinct, in consequence of its source being cut off.

According to Dr. Hall, the same principle explains the greater influence of certain respiratory acts (such as yawning, sneezing, coughing, &c.) on paralytic limbs, and

also the greater susceptibility of the paralyzed muscles to the influence of strychnia in cases of cerebral paralysis. It is obvious that in case Dr. Hall's views are confirmed by experience, the greatest advantage might be derived from the application of galvanism in doubtful cases of cerebral and spinal paralysis.

The first who objected to Dr. Hall's theory, was Dr. Pereira, who, in 1841, made a number of observations on paralytic patients, which convinced him that in certain cases of hemiplegia the muscles of the paralyzed limb were comparatively but slightly affected, while those of the healthy limbs were most powerfully convulsed.* In 1845, Dr. Copland also stated, that in cases of cerebral paralysis the paralytic muscles were not more irritable than the sound muscles, but, on the contrary, less so.† The most elaborate criticism, however, of Dr. Hall's theory has been given by Dr. Todd, in a paper on the contractility or irritability of the muscles of paralyzed limbs and their excitability by the galvanic stimulus, in comparison with the corresponding muscles of healthy limbs.‡

In order to refute Dr. Hall's view of the brain being the exhauster of muscular irritability, Dr. Todd pointed to the physiological fact that the healthy action of a muscle is promoted by exercise within reasonable limits, and that whatever restricts that exercise is injurious to

* Elements of Materia Medica and Therapeutics, 2nd edition, vol. ii. p. 1300.

† A Dictionary of Practical Medicine, vol. iii. part i. p. 42.

‡ Medico-Chirurgical Transactions, 1847.

the nutrition of the muscle, and consequently to its irritability. He afterwards adduced the evidence of thirteen cases of cerebral paralysis, to prove that in certain morbid states of the brain, the contractility or irritability of the muscles of the paralyzed limbs is not augmented. Dr. Todd used all kinds of currents in his experiments, viz. the continuous current, the current induced by voltaic electricity, and the magneto-electric current; and he observed that the results of the experiments were not in any way affected by the instrument employed. He observed that in a certain number of cases the paralyzed muscles responded very readily to the galvanic stimulus, and even displayed a greater amount of vigour than the muscles of the healthy limbs; and that in these cases the muscles of the palsied limb always exhibitcd some degree of rigidity. The vigour of their action in obedience to the galvanic stimulus was proportionate to the amount of rigidity within certain limits. In another class of cases, the stimulus produced little or no contraction; these were generally cases in which the muscles appeared more or less wasted. In a third class of cases he found that, while the paralysis was almost complete, the galvanic stimulus excited equally the muscles of the paralyzed and those of the healthy limbs; these were generally cases of apoplexy occurring in persons previously healthy and not advanced in years.

Dr. Todd also observed that the state of the muscles has comparatively little effect in the production of these phenomena; but that the effect of galvanism is due to the

state of nervous force in the paralyzed limbs. Thus in cases where the stimulus produces little or no contraction, the nervous force is *depressed* in the nerves of the paralytic limb; in cases where the galvanic stimulus excites contractions of a more lively character in the muscles of the paralyzed limb than in those of the healthy limb, the nervous force is *exalted;* and in the third class, where there is no perceptible difference between the two, the nervous force is in its *normal* height. He therefore concluded that galvanism may, in cases of hemiplegia, serve as a test to distinguish between an irritant and a depressing lesion of the brain, but not as a means of distinguishing between cerebral and spinal palsy.

In 1850, Dr. Duchenne published a paper on the state of electro-muscular sensibility and contractility,* in which he strongly objected to the mode of experimentation employed by Dr. Marshall Hall, and stated that the only way to arrive at a satisfactory result was to localize the electric current in the tissue of the paralyzed muscles. He gave as the result of his experience that the muscular contractility is always normal in cerebral paralysis, and that there is no difference between the muscles of the healthy and of the paralytic limbs. This statement I can only ascribe to the circumstance, that Duchenne has tested the muscular irritability of cerebral paralysis, in a few cases only, and that these happened to be such as are described by Dr. Todd in the third class of cases, in which the muscles retain their normal condition.

* Archives générales de médecine, 1850. Vol. xxii. p. 4.

I have tested the muscular irritability in nineteen cases of cerebral paralysis, and have arrived at exactly the same results as Dr. Todd. In a certain number of cases the contractility is diminished, the muscles are flaccid, and the polarity of the nerves depressed. In another class of cases the contractility is increased, there is early rigidity of the muscles, and an irritative lesion of the brain; in a third class of cases there is no difference to be observed in this respect between the healthy and the paralytic limb. In the cases in which I have tested muscular excitability I have employed both modes of experimentation, viz. sending the current right through the limbs, and localizing the current in the tissue of the muscles. Both methods yielded nearly the same results; but by localizing the electric current in the muscles the difference of muscular contractility appeared more striking.

I shall now relate a few cases, which may serve as representatives of the three classes which are to be distinguished in paralysis resulting from brain disease.

1. *Case of hemiplegia resulting from apoplexy. Muscular contractility diminished.*

R. V., Esq., aged 57, of originally vigorous and plethoric constitution, but now somewhat debilitated by an antiphlogistic treatment; has never been subjected to any serious illness, with the only exception of pneumonia, from which he soon recovered. Six months ago he had an apoplectic attack, accompanied with loss of consciousness for nearly three hours, and with paralysis of the right

side of the face, the tongue, the right arm, and leg. He did not know how this attack was brought on. He had sometimes suffered from palpitation of the heart, but the sounds and the volume of the heart are quite normal. He had not indulged in excesses of any kind; but his father died from apoplexy. The paralysis of the face soon disappeared, and the muscles of the arm and leg also regained some mobility. He writes, however, only with a quivering hand, and cannot well manage to hold spoon, fork and knife; he complains chiefly of his walking being greatly impaired.

His judgment and memory are not in the least disturbed; no pain in the head nor limbs. The cheek is not drawn to the side, nor does the tongue deviate from the median line. The movements of the eyes are quite normal. The speech is not impaired. The skin of the right arm and leg is cold and flaccid. Pulse 76, weaker in the right than in the left side. As to the state of sensation, there is a feeling of numbness in the right arm and leg, and they are not so sensitive to the prick of a pin as they ought to be. The muscles of the right arm and leg are relaxed and diminished in bulk. The motion of the extensors is chiefly impaired, while the patient can grasp pretty well. There is not the least rigidity of the muscles, neither in the upper nor in the lower extremity. Passive extensions of fore-arm upon the arm, and of the leg upon the thigh, may be done without any resistance felt on the part of the muscles. The galvanic stimulus, administered in a moderate dose, and with slow intermit-

tences, did not excite any motion in the paralyzed extensor muscles of the right arm, while the current of the same intensity and equally slowly interrupted, excited quite distinct motion in the muscles of the left arm.

The diminished state of muscular contractility, together with the other symptoms of the patient, allowed the conclusion that there was no longer any intracranial irritation; and as six months had elapsed since the attack, the cyst was probably formed. As it may be fairly supposed that in such cases not unfrequently the seat of the paralysis is no longer in the brain, but in the muscles which are impaired by the long rest they have necessarily taken after the attack,—paralysis from desuetude—I saw no objection to the electric treatment, and applied a moderate and slowly-interrupted current, by means of moist sponges lodged in metallic cylinders, the electrodes being held as close as possible to each other. The nutrition of the muscles was much improved by the treatment, as after sixteen séances the bulk of the muscles was increased, the circulation was reintegrated, the heat was the same in both extremities, and no difference was to be felt in the pulsations of the right and left radial artery. Writing as well as walking had become much easier, although not yet quite so easy as it had been before the attack.

2. *Case of hemiplegia; irritation of the brain; augmented excitability of the muscles.*

In December, 1858, a patient of the name of King was under the care of Dr. Todd, in King's College Hos-

pital; he had had repeated attacks of apoplexy, and probably suffered from a tumour in the brain, which kept up continual irritation. The patient suffered at that time from ptosis of the left upper eyelid, and from paralysis of the right side, with marked rigidity of the flexor muscles. I tested the excitability of the muscles, and found it slightly increased in the paralyzed leg, and very much increased in the paralytic arm. When I directed a gentle current to the belly of the extensor communis digitorum of the paralyzed fore-arm, a sudden and powerful extension of the fingers took place, which were before firmly closed by rigidity of the flexors; the same current directed to the non-paralyzed side did not induce any movements in the fingers, and I had notably to increase the intensity of the current to produce the same amount of contraction as in the paralyzed side. As to the direction of the current, I may mention, that the *inverse* current excited somewhat stronger contractions in the paralyzed side than the direct; and the *direct* excited somewhat stronger contractions in the sound side than the inverse. These experiments were repeated several times and always with the same result, in the presence of Dr. Todd, Dr. Conway Evans, and a large number of students.

3. *Case of hemiplegia; normal excitability of the muscles.*

L. T., aged 62, has long been in a gouty condition, and had an apoplectic fit seven years ago; in the attack speech and consciousness were lost, and a complete paralysis of the left side had existed for nearly six months,

after which time a gradual improvement took place. At present the speech is still impaired, walking is troublesome, and the motion of the left thumb and fore-finger very limited. Although these two fingers have scarcely been used for seven years, the excitability of the extensor and abductor muscles of these fingers is quite normal, as the muscles move freely under the influence of a gentle current. The same was observed in the recti of the thighs.

There is no other form of paralysis except that produced by an irritative lesion of the brain, in which the excitability of the paralyzed muscle is exalted. *If, therefore, the muscles of a paralytic limb are, by a current of the same intensity, more powerfully convulsed than those of the sound side, we may fairly conclude that the paralysis is due to brain disease, and that the lesion is of an irritative character.* But the excitability of the muscles is by no means augmented in *all* cases of paralysis resulting from a lesion of the brain; and therefore the distinction established by Dr. Marshall Hall between cerebral and spinal paralysis can no longer be admitted as conclusive.

Spinal Paralysis (Dr. M. Hall,) *Traumatic Paralysis* (Duchenne and others.)

Dr. Marshall Hall has termed spinal paralysis that which is observed when the muscle is functionally separated from the cord; as, for instance, by mechanical injury to a nerve. This peculiar view taken by Dr. Hall has naturally been almost generally misunderstood; as nearly

all electricians have taken what Dr. Hall calls spinal paralysis for equivalent with disease of the spinal cord. But according to Dr. Hall cerebral paralysis can be caused by disease of the spinal cord; if, for instance, the dorsal portion of the cord be injured, the muscles, animated by nerves which take their origin from the injured portion, present *spinal paralysis*, while the muscles, animated by nerves which arise from that portion of the cord which is below the seat of the lesion, present *cerebral paralysis*, as they are merely separated from the influence of volition, but remain in their functional relation with the cord.

The paralysis which Dr. Hall has termed spinal, has been termed traumatic by Duchenne and others. They agree, however, that in such cases the excitability of the muscles is diminished or even totally lost; in cases of this kind which have come under my notice I have observed the same condition.

4. *Case of Traumatic Paralysis of the facial nerve.*

S. W., Beverley Ward, St. Mary's Hospital, under the care of Mr. Ure. The history of this case is somewhat obscure, as the patient is deaf in both ears, cannot well read, and her relatives have described very little of her previous state. It appears, however, that her husband on several occasions bruised and mutilated her, and that once a severe blow was inflicted on the head. The patient complains of head-ache; the muscles of the left side

are paralyzed, and the prick of a pin is very obtusely felt on the skin of the same side. I applied the electric current locally to the different muscles of the face, but although I used a strong current, scarcely any contractions were to be observed in the paralyzed muscles; while the sensation excited by galvanism was intense.

The loss of muscular contractility is in some instances a very valuable guide to diagnosis. Thus Duchenne has recorded a case, in which he noticed loss of the contractility in the paralyzed muscles of the shoulder, by which he was led to the diagnosis of local injury to the nerves; and afterwards a syphilitic exostosis was discovered, which compressed certain branches of the cervical and brachial plexus. In most instances the excitability of the muscles appears to be lost very soon after the lesion of the nerve has occurred.

In cases of atrophy of the cord the electro-muscular contractility is usually diminished in the affected muscles, but sometimes it is quite normal, although the bulk of the muscles may have notably decreased and they refuse to obey the orders of volition.

Hysterical paralysis.

We not unfrequently meet in hysterical women with a more or less complete paralysis of the lower extremities, which is usually caused by anxiety or excitement. Cases of hysterical hemiplegia are of very rare occurrence. According to Duchenne, in all cases of hysterical paralysis the electric excitability of the muscles is normal, but

the electro-muscular sensibility (that is, the sensation excited by the electro-muscular contraction) is nearly or totally gone. In this I cannot agree with Duchenne, as I have found that in a certain number of cases of hysterical paralysis—both paraplegia and hemiplegia—the excitability of the muscles is considerably diminished, especially in cases where the affection is of long standing. Duchenne's assertions are generally correct for recent cases.

5. *Case of hysterical paraplegia; diminished excitability of the muscles.*

In May, 1858, at the request of Dr. Todd, I galvanized a lady, aged 28, unmarried, who had nearly lost the use of her legs in consequence of a fright. Her gait was staggering, and when not sufficiently supported the limbs gave way and she fell heavily to the ground. The disease wandered about the limbs, sometimes attacking more the right, at other times more the left, limb; for a short time the right hand also became affected, and writing and playing on the piano became very tiresome. When I first saw her she dragged the right leg as a piece of inanimate matter; the foot swept the ground, and being inclined to turn inside, the inner edge of the shoe was generally torn after it had been used for a very short time only. When sitting, she was scarcely able to raise the foot or to turn it outside, nor to move the toes; she experienced very great difficulty in getting up from the sitting posture, also in getting into bed at night; and she found

it almost impossible to press the pedals of the piano and the harp. On administering a gentle electro-magnetic current to the rectus of the *left* thigh the muscle was immediately seen to contract; but the same current proved utterly incapable of moving the rectus of the *right* thigh, and although I notably increased the intensity of the current, whereby a strong sensation was produced, only feeble vibrations appeared in the fibres of the left rectus. The same state was observed in the peronei and tibiales muscles; and it was only after sixteen electro-magnetic séances that the nutrition was so far restored that all the muscles of the right limb were equally affected by the electric current as were those of the left.

Lead-palsy.

Lead gets into the blood either by inhaling it through the lungs, as is done, for instance, by persons sleeping in newly-painted rooms, or it may become absorbed by the skin; in other instances it is taken with the food, especially in the adulterated wine and beer; and recently many cases have been recorded in which the lead passed into the blood of the patients, by their taking snuff which had been packed in lead-foil. The paralysis, which is the consequence of lead-poisoning, always affects certain sets of muscles, leaving others nearly or totally intact. The arms are almost always affected, while the lower extremities remain comparatively free from the disease; in the arm the flexor muscles are spared and the extensors are attacked. Generally the extensor communis digitorum is

the first which becomes affected; afterwards the extensors of the fore-finger and of the little finger begin to suffer; and lastly, the extensores carpi radialis and ulnaris, the triceps and deltoid, and the muscles of the ball of the thumb are affected. In cases of this kind the excitability of the muscles is always very much diminished, and often entirely lost; such is the case not only when atrophy has been the consequence of the lead-poisoning, but also when the bulk of the muscles is only slightly diminished; and the excitability of the muscles, in certain instances, remains still impaired after the voluntary movements have regained their former power.

6. *Case of lead-palsy; excitability of the muscles gone.*

Samuel R———, painter, aged 28. He has had several attacks of lead-colic, from which he recovered under medical care. Six weeks before I saw him, he had pain in the joints and cramps in the legs. He now complains of the dropping of the left hand, also of obstinate constipation. A blue line on the gums is distinctly visible. All the extensor muscles of the left fore-arm as well as the deltoid are paralyzed; the left arm and the fingers cannot be lifted. But if the first phalanges are supported, the patient can extend the second and third phalanges; which proves that the interossei and lumbricales have not suffered. The back of the fore-arm is concave by atrophy of the extensors. The raising of the arm is difficult, and the extending to a right angle with the body is impossible. The flexor muscles are not affected. The right arm

is weak, but not paralyzed. The lower extremities are not impaired. On applying an intense current to the deltoid muscle, only a little tremulousness appears in its fibres, which are wasted, and in the extensors on the back of the fore-arm no contraction was to be produced. I galvanized the patient every other day, for about four weeks, after which he regained much more strength in the muscles, the volume of which had considerably increased; still the excitability of the extensors of the left arm was much less than that of those of the right.

To prove the value of galvanism as a means of diagnosis in cases of this kind, I may here add another case of paralysis of the fore-arm, which was not caused by lead-poisoning.

7. *Spontaneous paralysis of the extensors on the back of the fore-arm; excitability normal.*

W. W., out-patient of St. Mary's Hospital, was sent to me by Mr. Edwards. Without any premonitory symptoms having been observable, the patient, about a fortnight before I saw him, found, on awakening in the morning, that he could not move the right arm; the hand drops, the lateral movements of it are also lost, and the sensibility of the skin on the back of the fore-arm is impaired. Neither lead-poisoning, nor concussion of the radial or ulnar nerve, rheumatism, disease of the brain, fatty degeneration, or atrophy of the muscles, is present. No pain, but numbness is complained of, and all the extensor muscles excited by the lower branches of the radial nerve

have lost their energy. The excitability of these muscles is not at all impaired, but scarcely any sensation is produced by the electro-muscular contraction. When I directed the electric current to the paralyzed muscles of this patient, he felt them move, but although I applied the most rapid intermittences of a very intense current, not the least pain was felt, while the same current applied to the healthy muscles of the left fore-arm produced an extremely disagreeable and almost tetanic sensation. I ought not to omit mentioning that for acquiring an exact knowledge of the state of this sensation, it will not do to compare the sensibility in the paralyzed extensors with that of the healthy flexors of the same fore-arm, as the skin on the anterior side of the fore-arm is much more delicate, and therefore offers much less resistance to the passage of the current than the skin on the back of the fore-arm. Therefore, in experiments of this kind, only the corresponding muscles of the right and of the left side are to be compared.

The difference in the general aspect of the cases 6 and 7 may be easily observed. But the symptoms of the effects of lead upon the system are not always so distinct as in case 6; indeed, sometimes the dropping of the wrist is the first symptom of the lead-poisoning. The diagnosis, however, between lead-palsy and cases like 7, has not only a theoretical but also a practical interest, as in lead-palsy the application of electricity must be combined with a general treatment, while local palsies without structural changes generally soon disappear when treated

by galvanism only. When a patient states that he has never been exposed in business to the injurious influences of lead, we cannot therefore conclude that the paralysis is not caused by lead-poisoning; as lead is often administered to the system for a length of time in adulterated food and drink without the patient's having the least knowledge of it. Nor is the paralysis of the extensor muscles always preceded by, or simultaneous with, symptoms which belong to the constitutional disease, and will, if observed, facilitate the diagnosis. Only the relation of the muscles to the electric excitation helps, in doubtful cases, to establish the diagnosis, as the excitability of the muscles is always either lost or diminished in lead-palsy, whilst it is normal in spontaneous paralysis. Therefore when the muscles of a paralytic limb move well under the influence of the electric current, we may fairly conclude that there is no lead in the system.

Rheumatic paralysis.

In this form of paralysis the electro-muscular contractility is, according to Duchenne, quite normal, while the sensation excited by the electro-muscular contraction may be even stronger on the suffering side than on the healthy parts. This is true in cases of short standing; but in cases of long standing, I have almost invariably found the excitability of the muscles impaired.

Wasting palsy.

The excitability of the muscles is, in this disease, quite proportional to the more or less atrophic state of the mus-

cular fibres. The more the bulk of the muscle is diminished, the weaker is the contraction exhibited by it. In this disease electricity enables us to distinguish the state of almost every muscle and bundle of a muscle, whether normal or atrophied. Thus, for instance, I have seen cases in which the whole substance of the extensor communis digitorum was not atrophied, but merely that portion of the muscle which extends the middle finger. This was easily distinguished by placing the electrodes of an induction apparatus upon the belly of the extensor communis, when only the fore-finger, the fourth, and the little finger were extended, while the middle finger remained quite or nearly motionless. The same is often to be observed if we galvanize the interossei and lumbricales, when only one or two of the muscles will respond to the electric current, while the remaining ones are not affected, unless a very intense current be used.

We have thus arrived at the result that the muscles of paralyzed limbs may present three different conditions when subjected to the action of the electric current, and that this may enable us in certain cases to form the diagnosis of the paralyzing lesion.

1. If the excitability of the muscles—or rather the polarity of the motor nerves—be *increased* in the paralyzed limb, the case is one of *cerebral paralysis*, connected with an irritative lesion within the cranium.

2. If the excitability of the muscles be nearly or totally *lost*, we have in all probability either *lead-palsy* or *traumatic paralysis;* but it must be kept in mind that certain

hysterical and rheumatic palsies of long standing present the same peculiarity; and that it also may be found in cases of disease of the brain and the cord.

3. *If paralyzed muscles respond readily to the electric current*, there is no lead in the system, nor is the connexion between the motor nerves of the paralyzed muscles and the cord interrupted; but if such cases are of *long standing*, they are due to *brain disease;* and if they are of *recent standing*, they are generally instances of *hysterical*, *rheumatic*, or *spontaneous* paralysis.

CHAPTER V.

ELECTRO-THERAPEUTICS.

As a therapeutical agent galvanism may be of service not only in medicine, but also in surgery and midwifery. In medicine electricity has been successfully employed in the treatment of certain paralytic and spasmodic diseases, and of hyperæsthesia and anæsthesia; it has been used, besides, for the absorption of rheumatic callosities, and as a means of transport to convey medicinal substances into, and extract such substances out of, the human body. In surgery, electricity may be used for producing the coagulation of blood in aneurisms and varices; for the dissolution of urinary calculi; for actual cauterization; for the treatment of ulcers, and the absorption of exudates. In midwifery galvanism has been found useful as a stimulant in cases of tedious labour arising from uterine inertia, and in certain instances of hemorrhage from the uterus.

Therapeutical use of electricity in medicine.

We have seen in the second chapter that, whatever may be the properties of the nerves, they can be called into action by galvanism; and that we are able by merely varying the modes of applying electricity to arouse or to

diminish the vital properties of the nerves. From this it may be understood that electricity can be used as an excitant of muscular power in paralytic diseases; and of sensation, in anæsthesia; and that, on the other hand, it may be of service in subduing spasms and in reducing a morbid increase of sensibility, as is the case in neuralgia. But it must not be supposed that electricity can be successfully applied in every case of paralysis, spasm, neuralgia, and anæsthesia; in fact, if electricity were indiscriminately used in all such cases, as has been done in former times, much more harm would eventually be done by it than benefit bestowed. The reason for this is that loss of power, spasm, anæsthesia, and neuralgia are by no means well-defined diseases, but merely *symptoms of diseases*, to which the most various disorders may give rise. It is, therefore, necessary to pass in review the various causes which may occasion loss of power, spasm, anæsthesia, and neuralgia; whence we shall be enabled to judge in which instances electricity may be administered with a fair chance of success.

I. *Treatment of paralysis by electricity.*

Paralysis may be caused by various diseases of the centre of volition, especially by hemorrhage into, and rupture of, the fibres of the *brain;* whereby the normal connexion between the brain and the motor nerves is destroyed, so that the orders of the will are no longer transmitted to the muscles, which are, therefore, incapable of executing voluntary movements. Now the question arises

if the electric current has any power of acting upon the brain of living man, and if so, whether we are allowed to employ it in palsies directly arising from brain disease? The brain and the spinal cord are surrounded by membranes and bones which offer a very great resistance to the passage of electricity; and they are inaccessible to electricity, unless a current of such high tension is used which would be dangerous to the patient. It has been rendered probable by the researches of M. Bonnefin* that if a very powerful current be applied to the sentient nerves of the skin by means of metallic excitors, a very feeble current may pass through the nervous centres. But even conceded that we may send a very feeble current through the brain, this does by no means prove that any advantage could accrue from such a proceeding. There is no well-established fact which justifies us in assuming that hemorrhage into the brain, and atrophy and softening of the cerebral substance, could in any way be beneficially affected by electricity. On the contrary, it is amply proved by experience that such diseases are aggravated by its administration. Duchenne† has recorded a number of cases, in which by the injudicious application of electricity to patients who had suffered from hemorrhage into the brain, another apoplectic attack was caused.

Nevertheless electricity may be of great service in certain instances of paralysis, originally arising from a lesion of the brain. In order to understand this we must ana-

* Journal de Physiologie, par M. Brown—Séquard, No. III.

† De l'électrisation localisée, etc., p. 724.

lyze the pathological process of reparation which is caused in the brain, if the patient has survived the apoplectic stroke. It is obvious that when an extensive laceration of cerebral tissue has taken place, the paralysis will, in all probability, remain permanent. But when there has been merely an effusion of blood, the symptoms are rather caused by the clot compressing and separating the cerebral substance than by destruction of brain tissue; although it is quite true that hemorrhage into the brain is almost always accompanied with a certain amount of rupture of brain fibres. In cases where the symptoms of paralysis are principally caused by a clot, the patient's health may be perfectly restored. At first the fluid parts of the blood effused into the brain are absorbed, and an organized membrane, a cyst, is formed around the clot, which in the course of time is likewise absorbed. The cyst then shrinks up, and at last only a cicatrix is to be found. In a certain number of cases this process of reparation is accompanied by a gradual amelioration of the paralytic symptoms, and thus a spontaneous recovery may take place. In other instances, by the gradual shrinking of the cyst, an irritative condition is kept up in the brain, and the paralyzed muscles then assume a rigid condition. Finally, the cicatrix may have been formed, and there may be no rigidity of the muscles, but the paralysis still continues in a more or less degree. Now, when there has been an extensive laceration of cerebral substance, and when by the shrinking of the cyst rigidity of the paralyzed muscles is induced, the para-

lysis depends upon central injury, and an electric treatment would only tend to aggravate the symptoms. It is also evident that if symptoms of spontaneous amelioration are observed, there is no need of electricity. But if we have reason to believe that the cicatrix may have been duly formed, and nevertheless the paralysis continues, the electric current may be employed with a fair chance of success, and should be localized in the paralyzed motor nerves and muscles.

I need not mention that if the paralysis depends upon morbid growths compressing the cerebral substance, there is not the slightest reason for the application of electricity.

Paralysis may be caused likewise by inflammation and atrophy of the *spinal cord*. These are the cases which Dr. Remak professes to cure by means of the continuous current; but I am afraid that either he has been mistaken in the diagnosis of his cases, or that he has been subjected to strange illusions as regards a cure. In my opinion, palsies depending upon a diseased condition of the spinal cord are scarcely ever amenable to electricity, as the central lesion tends only in a very limited number of cases to a spontaneous amelioration, but generally proceeds unchecked in its fatal course. If the lesion of the cord be of recent date and progressing, the symptoms are aggravated by an electric treatment.

Local palsies are much more amenable to electricity than palsies arising from a central injury. But not even every local palsy is likely to be ameliorated or cured by

electricity. Thus a local palsy may be caused by some injury which has happened to the motor nerves, wounds, concussions, pressure, etc. Electricity has no influence to further the re-union of the fragments of a nerve, or to check an inflammation of the sheath of the nerve; but if a process of reparation has taken place, and the excitability of the nerve still remains enfeebled, electricity may restore it to its normal condition.

Besides, there are other kinds of palsies in which neither the nervous centres nor the motor nerves have been palpably injured. Cases of this kind are often wonderfully amenable to electricity. To this class belong cases of hysterical paralysis, rheumatic paralysis, lead-palsy, incomplete paralysis of the lower extremities, connected with disease of the urinary organs; cases of paralysis remaining after acute diseases, such as typhus, cholera, and cases of spontaneous paralysis, in which it is impossible to distinguish the cause of the lesion. Finally, cases of perverted nutrition and atrophy of the muscular substance are almost always beneficially affected by the application of electricity.

I now proceed to consider the question, *how it is that galvanism acts beneficially in paralytic diseases;* a question which up to the present time has not been satisfactorily answered. It is obvious that we can only arrivo at a satisfactory solution of it, if we draw our conclusions from the established principles of electro-physiology, coupled with therapeutical experience.

First proposition.

The galvanic stimulus is capable of disturbing the molecular equilibrium of the motor nerves and muscles, so as to produce the state in which they are physiologically active. This disturbance, if judiciously produced, does not cause any injury, but tends to re-establish or to ameliorate the lost or impaired vitality of the motor nerves and muscles.

As the first part of this proposition flows directly from what has been described in the chapter on electro-physiology, I need only say a few words on the latter part of it, which is an induction from my therapeutical experience.

There are two sorts of paralytic diseases which are often beneficially affected by the application of electricity, in which by this proposition only we are able to explain the success of the treatment. I allude, in the first place, to cases in which the excitability of the paralyzed muscles to the galvanic stimulus is completely *preserved;* and, in the second place, to cases in which the excitability of the paralyzed muscles is totally *abolished.* Now if, as has often been contended, galvanism acted beneficially only by producing contraction, and thus improving the nutrition, of the paralyzed muscles, cases like those just mentioned could not posssibly be ameliorated or cured by electricity; since in the former class of cases the nutrition of the muscles is perfect, as they respond freely to a gentle current; and in the latter, no contraction of the muscles is produced. I have seen cases of cerebral and hysterical paralysis, in which the paralyzed muscles had quite preserved their contractile power, considerably and rapidly

ameliorated by the application of electricity. I have also cured cases of rheumatic and of spontaneous paralysis, in which the nutrition of the muscles was not in the least impaired. It is possible that in such cases the paralysis depends upon a diminution or perversion of the current proper of the nerves and muscles, and that the current proper is restored to its normal condition by the application of electricity.

On the other hand, cases of lead-palsy and of traumatic paralysis are cured by electricity, although in the commencement of the treatment even a current of very high tension does not cause any movements whatever in the paralyzed muscles. In such cases the beneficial effect cannot be explained by the electric current producing contraction of the paralyzed muscles; for no contractions are produced; nor by the current causing an increased supply of arterial blood to the limbs; for no increase is observable, either in the temperature or in the bulk of the muscles; but only by the supposition that the current restores that mobility to the molecules of the nerves and muscles which is necessary to enable them to be physiologically active.

Second Proposition.

The galvanic stimulus allows the necessary alternate contraction and expansion of the muscles, without which their nutrition is generally soon seriously impaired.

This fact having never been called in question, I merely adduce the evidence of the observations of Dr.

John Reid, which have been related in the second chapter of this volume.

Third Proposition.

The galvanic stimulus, by producing contractions of the muscles, and thus augmenting the chemical changes in, that is, the oxidation of, the muscular tissue, causes a more abundant supply of arterial blood to it, which is evidenced by an increase of heat and bulk in those parts which have been galvanized, and which in its turn augments the nutrition of the muscle.

This proposition has been fully proved in the second chapter of this volume.

To sum up, galvanism acts in paralysis by restoring the lost mobility to the molecules of the nerves and muscles, and by causing contraction of, and a more considerable supply of arterial blood to, the paralyzed muscles.

It now remains to determine the form of electricity which should be applied in paralytic diseases, the direction in which the current should be passed, the intensity of the current, and the length of time its action should be kept up.

As to the *form of electricity to be used in paralysis*, we must act in accordance with the electro-physiological law first established by Du Bois-Reymond, viz. that the motor nerves are not excited by the absolute amount of the density of the current, but merely by the variations which occur in the density of the current from one instant to the other; and that the amount of excitation caused is

proportionate to the rapidity with which these changes take place. Hence it results that the continuous current should not be used in the treatment of paralysis, but only induction currents, which consist of great and sudden variations, and are thereby capable of exciting the vitality of the motor nerves to the highest degree.

A singular objection has been raised by Dr. Golding Bird* against the current induced by voltaic electricity being an antiparalytic remedy. Dr. Bird thinks it necessary that the current should be sent through the paralyzed muscles in the same direction in which the current proper of the muscles travels in the limbs. Now, he asserts that currents induced by voltaic electricity should not be employed for paralysis, as they are alternately guided in contrary directions. It is easy to refute this objection. In the first place, it is by no means proved that it is really necessary to send the current through the limbs in that particular direction; and in the second place, the physiological effect of the current induced on *making* the circuit is so extremely feeble that it must be disregarded altogether in therapeutical applications; it is only the current induced on *breaking* the circuit which exercises a remarkable physiological and therapeutical effect, and this current moves in a direction equal to that of the current of the battery.

Dr. Remak† of Berlin has recently published an ac-

* Lectures on Electricity and Galvanism, &c. London. 1849.

† Galvanotherapie der Nerven—und Muskelkrankheiten. Berlin, 1858.

count on the therapeutical action of the continuous current, which, according to him, is the true antiparalytic remedy, and especially useful in brain disease and atrophy of the spinal cord, in which complaints the most wonderful cures are said to have been obtained by him in an incredibly short time. During a visit to France, Dr. Remak made some therapeutical experiments with the continuous current before colleagues in Paris, on the results of which Dr. Déchambre has given the following report in the Gazette Hebdomadaire:

"From four patients galvanized under our eyes, two were in such a condition that we should have been much surprised to see any improvement produced in a few moments. The first was a case of general wasting palsy, especially marked in the upper extremities. The muscles of the shoulder were electrified, but the movement of elevation of the arm has thereby not become easier. The second had a treble lateral curvature of the spine, in consequence of a deviation of the pelvis to the left side, resulting from sciatica. It was tried to redress the middle and inferior curvatures by the excitation of the muscles in the convexity; but without any appreciable result. The two other cases seemed to offer more chances; for in the one there was an incomplete paralysis of the deltoid, in a very young man, in consequence of a contusion; in the other, paralysis of the extensors of the hand, ascribed to a cause of the same kind; but here also no effect was produced."

I may also mention, that Dr. Niemeyer* of Magdeburg

* Deutsche Klinik, July 5th, 1858.

has used the continuous current in apparently very favourable cases of hemiplegia, and followed the directions given by Dr. Remak, but without the slightest success, so that at present the therapeutical value of the continuous current in paralytic diseases appears to be extremely doubtful.

No rules are at present fixed as to the *direction* in which the induced current should be sent through the paralyzed limbs. We know that the current in the arm of man travels from the shoulder towards the hand; hence it has been concluded that it would be best to send the induced current through the nerves in the same direction; that is to say, to use the *direct* current. On the contrary, Matteucci has recommended that in paralysis of motion the current administered should be *inverse;* as he supposes that the nerves of the affected limb might be in a condition similar to that which is caused by the prolonged passage of a direct continuous current through a limb; and as we may by administering an *inverse* current to the nerve of a frog's leg restore to the nerve the excitability which it has been deprived of by the passage of the *direct* current, so Matteucci supposed the current would more readily relieve the paralysis of motion in man, if it were sent through the motor nerves, which act centrifugally, in the inverse or centripetal direction; while paralysis of sensation would require the centrifugal or direct current, since the sentient nerves act centripetally. However ingenious this theory may be, there are no proofs whatever of its being correct; and its practical

value seems to be very doubtful. Besides, it applies strictly to the continuous current only, and not to the induced current. A more palpable reason for employing the inverse current in the treatment of paralysis is, that in many cases of paralysis the inverse current excites stronger contractions in the muscles than the direct; hence it appears justifiable to use the inverse current with preference in such cases. It is, however, important to change now and then the direction of the current, as by the continued passage of a current always guided in the same direction, the motor nerves and muscles are more fatigued than if the position of the poles be sometimes reversed.

As to the *intensity* of the current to be employed, it is necessary exactly to measure the dose which may be convenient for each case; therefore we should always begin with a very gentle current and gradually increase its intensity, so as to produce, if possible, decided contractions of the paralyzed muscles. Severe shocks, especially in the commencement of the treatment, should be carefully avoided, as by such the weakened excitability of the motor nerves may be still further reduced.

No general directions can be given as to the *duration* of each séance, which must be left to the judgment of the electrician. Some cases require long applications, others do better if the séances be not of too long duration. Generally speaking, however, the electric current should not be administered for more than a quarter of an hour each time.

The *number* of séances required to cure paralytic diseases is also very variable. Cases of hysterical paralysis not unfrequently require only a few applications of electricity. Thus I have cured a case of hysterical aphonia and two cases of amenorrhœa by only one séance each: other cases require a longer treatment, and in cases of wasting palsy or Cruveilhier's atrophy a very great number of séances must be held in order to arrest the disease and to ameliorate the patient's state.

I now proceed to consider some special forms of paralysis, which are amenable to electricity.

A. *Paralysis resulting from brain disease.*

We have already seen that some cases of this kind are likely to be benefited by electricity, while others are not; and that this depends entirely upon the pathological process which is going on within the cranium. To distinguish this, we must always look at the state of the paralyzed muscles, which has first been minutely described by Dr. Todd, in his admirable clinical lectures on paralysis, certain diseases of the brain, and other affections of the nervous system.

There are three principal classes of cases; in the first the muscles of the paralyzed limb are relaxed, the limbs loose and flaccid, and if the fore-arm is flexed upon the arm, or the leg upon the thigh, there is no resistance to that movement. The paralyzed muscles present a striking contrast to the firmness and plumpness of those of the sound side, and they are more or less wasted according to

the length of time which has elapsed since the paralytic seizure. In such cases there is generally very little response to the galvanic stimulus, and the heat and general nutrition of the limbs is much below par. Some of these cases recover of themselves, in others a partial recovery only takes place after a certain time. If four to six months or more have elapsed since the seizure, and the recovery is imperfect, it is justifiable to employ electricity in cases of this kind. It is, however, important that the electric current should be localized in those muscles which remain paralyzed and really require the stimulus. Therefore the excitors—moistened sponges lodged in metallic cylinders—are to be held as close as possible to each other on the skin, in order to limit the current in the muscles covered by it. When the excitors are held removed from each other, so that the electric current passes through the whole length of the limbs,—for instance, when one excitor is held in the right and the other one in the left hand; or if the feet of a patient be placed in two separate vessels filled with salt water and connected with the poles of a battery,—painful and irregular commotions are caused in the paralyzed and the healthy muscles, which are indiscriminately affected. Consequently, this method of operation can scarcely ever be beneficial to the patient. As to the intermittences of the induced current, they should be rather slow, whereby any irritation of the brain is avoided. I shall now relate a case, in which only a few muscles remained paralyzed after the paralytic seizure, and in which a considerable amelioration was effected by the faradic treatment.

Case 8.—Jane S., aged 35, Carlisle ward, St. Mary's Hospital, under the care of Dr. Alderson. From the rather confused remembrances of the patient, whose judgment is not much developed, it appears that she had an apoplectic attack fifteen months ago, in which she lost her consciousness and the use of the left arm and leg. It seems that the paralysis of the lower extremity soon disappeared. At least, when I saw her the first time, July 20th, 1857, she was not troubled in walking, but several muscles of the left arm were paralyzed, namely, the deltoid muscle, the extensor of the fore-finger, and all the muscles of the thumb. It is true that the mere elevation of the humerus could be effected by her, as in this movement the trapezius and the serratus magnus concur with the deltoid muscle, but she was not able to raise the arm to a right angle with her body, and when she held her hand on the lower part of the spine, she could not raise it upwards in the direction of the spine. The fore-finger was slightly bent, and could not be extended; the thumb was held against the fore-finger, and could not execute any movement whatever. The muscles named were quite flaccid, and the bulk of them considerably diminished. She was not able to do either washing or needle-work, or exercise her business as cook. When I directed the electric current to the paralyzed muscles, they showed very little excitability to the galvanic stimulus. The deltoid was much improved after five sittings, but the muscles of the fore-finger and the thumb wanted a longer excitation. About twenty sittings were held; after which the patient

left the hospital, being again able to do needle-work, washing, and to return to her business as cook.

In another class of cases, the muscles, which are paralyzed in consequence of brain disease, exhibit a certain amount of rigidity, which is especially remarkable in the biceps of the arm and the hamstring muscles of the thigh; and which varies from an increased plumpness up to a contraction almost tetanic. Dr. Todd has termed this the state of *early rigidity*, as it exists either from the moment of the attack or soon after it has taken place. In such cases the circulation in the limb is vigorous, the heat not below par, and the paralyzed muscles generally more excitable to the galvanic stimulus than those of the healthy limb. It is quite obvious that in cases of this kind there is not the slightest reason for the therapeutical application of electricity, which would in all probability aggravate the symptoms, arising from an irritative lesion of the brain.

Finally, the muscles may present the state of *late rigidity*. Muscles which have been flaccid and wasted for a certain time, gradually acquire more tension and become shortened. The tendency to assume this rigid state is more marked in the arm than in the leg, and more in the flexor muscles than in the extensors. It is generally caused by the gradual shrinking of the cyst, which operates as an irritant foreign body on the brain. In most of these cases the electric treatment should not be resorted to; but in some cases of long standing, an electric excitation of those muscles which are the antagonists of the

rigid muscles, may serve to restore the disturbed equilibrium between certain sets of muscles. The following case may serve to illustrate this:

Case 9.—In December, 1858, a man of the name of Marsh was observed in King's College Hospital, under the care of Dr. Todd. Four years ago he had had an apoplectic attack with consequent paralysis of the right side. The paralyzed muscles had then soon assumed a state of rigidity, which has not undergone any considerable change since that time. At present the patient can with some difficulty walk, but the right arm is perfectly useless, as there exists a rigidity of a number of muscles; viz. of the coraco-brachial muscle, whereby the arm is adducted to the side; of the biceps, so that the fore-arm is bent upon the arm; if forcible extension of the fore-arm is attempted, the biceps offers a certain resistance to it, but no pain is experienced during the forcible extension. Stiffness is also marked in the triceps, although much less than in the biceps; it becomes evident if a complete flexion of the fore-arm upon the arm is attempted so as to place the fingers on the acromion of the same side. The flexor muscles of the wrist and of the fingers are in a state of complete rigidity; the hand is strongly bent upon the fore-arm, and the fingers are firmly pressed against the palm of the hand, so that the patient is obliged to cut his nails very short, in order to prevent irritation of the skin by the growth of the nails. The tendons project like tight strings beneath the skin. The patient affirms, however, that he experiences no pain if a forcible extension of the wrist and of the fingers is

attempted. There is not much wasting in the muscles, but the excitability to the galvanic stimulus is very trifling in the extensor muscles of the fore-arm, while the flexors of the fore-arm contract very readily under the influence of a gentle current. The stiffness of the muscles of the lower extremity is much less considerable than of those of the arm; it is, however, distinct in the hamstring muscles and in the flexors of the toes; and in walking the patient drags the paralyzed leg.

I supposed that in this case the cyst might have shrunk to a very small volume, and that the disturbance in the equilibrium between the different sets of muscles of the upper extremity might no longer be exclusively due to the lesion of the brain, which was undoubtedly the primitive cause of it, but also in some measure to the long preserved overweight of the contracted flexors over the paralyzed extensors of the fore-arm; and I thought that by administering a convenient stimulus to the relaxed extensors the equilibrium between the two sets of muscles might possibly be restored. This view was confirmed by the result of the treatment; for after I had faradized the extensor muscles of the fore-arm for some time, the tendons of the flexors, which had before projected like tight strings beneath the skin, became soft and flexible; and the patient was able to open his hand and stretch his fingers; but having been some time afterwards exposed to a violent cold draught, the flexors again assumed a certain degree of rigidity. By further Faradization he again improved, but he left the hospital before a permanent relief was afforded.

B. *Local palsies of motor nerves and voluntary muscles.*

Of all the cerebral nerves the portio dura is the one most frequently affected with local paralysis. The three nerves which animate the muscles of the eye are also liable to this disease; but if there are symptoms of the eighth nerve being paralyzed, there is probably disease in that part of the brain where this complex nerve takes its origin.

1. *Palsies of the muscles of the eye.*

If the *third nerve*, or motor oculi, is paralyzed, the eyelid cannot be raised in consequence of loss of power in the levator palpebræ superioris muscle: this dropping of the upper eyelid (ptosis) is the most constant symptom of paralysis of the third nerve. Other signs of this affection are protrusion of the eyeball, and dilatation of the pupil, which cannot be turned inwards, while the outward movement is not impaired, since the rectus externus is animated by the sixth nerve. The upward and downward motion of the eyeball is limited or quite impossible; besides, there is double vision, and the accommodation of the eye for the vision of objects near the patient is impossible.

Local palsy of the *fourth nerve* is of very rare occurrence, and difficult to be recognised. Dr. A. von Graefe,* of Berlin, has observed that in this affection the pupil is turned a little upwards and inwards; when looking upwards the vision is not disturbed, but in looking at an object placed horizontally before the eye, the patient is

* Archiv für Ophthalmologie. Vol. i., p. 1.

troubled by double vision; and to avoid this, the head is generally turned towards the opposite side.

If the *sixth nerve* is paralyzed, the patient squints inwards, and is troubled by double vision in certain directions; sometimes the inward deviation of the eye is so strong that the whole cornea may be concealed at the inner angle of the orbit. This palsy generally occurs simultaneously with a similar affection of the third nerve; and then the globe can neither be moved upwards, nor outwards, nor downwards.

These palsies may be caused by brain diseases; but they have seldom been observed as only the symptoms of such diseases. They are more frequently caused by rheumatic or syphilitic exudations, and over-exertion, or want of exertion, of the muscles; tumours may also compress the substance of the muscles or nerves. Certain cases are incurable, others get well after they have existed for a certain time without any treatment whatever. The treatment generally adopted consists of, 1st, gymnastic exercise of the affected muscles, which is, of course, only possible, if the paralysis is incomplete; and, 2ndly, excitation of the skin in the neighbourhood of the eye. In cases which are traceable to over-exertion, or want of exertion, electricity deserves a trial. The faradic treatment of such palsies appears to be difficult and dangerous on account of the situation of the muscles inside of the orbit. Three different methods, however, have been adopted in the application of electricity to the paralyzed muscles of the eye, viz., by placing one electrode in the hand of the patient,

and touching the skin in the neighbourhood of the eye with the other electrode; by faradizing the branches of the trigeminal and facial nerves, in order to excite the nerves and muscles of the eye by a sort of reflex action; and, finally, by electro-puncture, viz., introduction of needles connected with the poles of a battery into the tissue of the paralyzed muscles. Dr. Meyer, of Berlin,* has recently proposed another way, viz., to place one electrode connected with the negative pole into the hand of the patient, and to apply a small moistened sponge connected with the positive pole to the skin of the closed eye, as close as possible to the paralyzed muscle. For exciting the rectus internus he held the positive electrode to the inner angle of the eye; and for localizing the electric current in the obliquus superior, he placed the positive electrode beneath the trochlea. In this way he treated a patient of Dr. A. von Graefe, who had suffered for five months from double vision in consequence of a paralysis of the rectus internus and obliquus superior; this patient was very much improved by electricity. In another patient who had suffered for four years from double vision, in consequence of the paralysis of several muscles of the eye, Dr. Meyer effected a complete cure within five weeks by the same means. In this palsy, more than in any other, the application of the continuous current should be carefully avoided, on account of its action upon the retina; and the extra-current of an induction apparatus

* Einige Fälle von Augenkrankheiten, etc. Deutsche Klinik, 1856, No. 38.

should be used, which has no action whatever upon the retina.

2. *Paralysis of the facial nerve.*

There are two different kinds of facial palsy; one arising from exposure to a draught of cold air, and generally caused by a rheumatic effusion, which takes place into the cellular tissue, between the facial muscles and the exterior branches of the portio dura, the other arising from injury to the intracranial portion of the facial nerve. In the former class of cases, the muscular and nervous fibres are compressed, and their function cohibited by the effusion; in such cases there is no destruction or inflammation of the nerve, and the paralysis disappears in proportion as the effusion is absorbed. Therefore it may happen that some of the facial muscles soon regain their normal power, while others will remain paralyzed; but if any injury has happened to the trunk of the portio dura within the cranium, the affection is almost invariably the same in all the physiognomical muscles. The absorption of the rheumatic effusion is often spontaneous, and many cases of facial palsy get well without any medical treatment whatever. In some cases amelioration is induced by blistering and the application of an ointment of iodide of potassium. In other cases these means prove insufficient to induce absorption of the effusion, which in time may become hard and callous. In all cases of this kind the electric stimulus is the best means of restoring the muscles to their normal state, by causing them to contract individually, and inducing a more or less rapid ab-

sorption of the effusion. Generally the excitability of the muscles to the galvanic stimulus is impaired, and the tone and the voluntary movements of the muscles return in proportion as the excitability of the muscles to the electric stimulus is restored.

In facial palsy the physiognomical expressions of surprise, terror, hilarity, threat, sadness, reflection, malice, disgust, and rage, vanish on the paralyzed side, and are exaggerated on the sound side; the patient is not able to frown, laugh, or whistle: besides which, certain changes in the features which depend upon the disturbance of the equilibrium between the paralyzed and non-paralyzed muscles take place. If the two sides of the face are paralyzed, the features appear as if covered by a mask, and the eyeballs only are capable of motion.

If the frontal portion of the *occipito-frontalis* muscle and the *corrugator supercilii* are paralyzed, the patient is not able to move the scalp nor to frown. Where the forehead is wrinkled, as is the case in old people, the transverse wrinkles disappear by paralysis of the frontal muscle, and the perpendicular wrinkles between the eyebrows vanish by loss of power in the corrugator. In certain cases the eyebrow is seen to drop and hang above the orbit; which gives the face a doleful, and in some instances a truly terrible, expression.

If the *orbicularis palpebrarum* is paralyzed, the eye cannot be shut; it is consequently always exposed to the air, even during sleep, whereby in many cases a state of irritation in the conjunctiva is caused. Tears flow freely,

and to such an extent that the skin of the cheek may be excoriated by them. The conjunctiva is often injected, but such changes in the nutrition of the cornea and of the conjunctiva as are observed in anæsthesia of the fifth pair never take place. The eye generally appears staring and protruded, the eyelids are further apart than is natural, and a large portion of the sclerotic is exposed to view; this is especially caused by the dropping of the lower eyelid. If the patient is told to shut the eye, either no motion is perceptible, or the eyeball is carried upwards and inwards beneath the upper eyelid, so that the cornea is partially or totally concealed; the latter movement being executed by the rectus internus, rectus superior, and obliquus inferior muscles, which are not animated by the portio dura, but by the third pair. The eyelids are apart, because the levator palpebræ superioris muscle, which is the antagonist of the orbicularis, retains its power, it being likewise animated by the third pair. Paralysis of the orbicularis does not occur in facial hemiplegia of central origin, so that if the eye cannot be shut, we may be sure that the case is one of paralysis of the portio dura, and not of cerebral paralysis.

In facial palsy the nostril is devoid of voluntary movements, in consequence of the paralysis of the *levator alæ nasi*, and *pyramidalis nasi*. Thus dilatation of the corresponding nostril becomes impossible, and it is kept open only by the rigidity of the cartilages of the nose.* The

* If in such animals, where the nose is quite soft, as is the case in horses, a section of the facial nerve has been made, the nostril appears

respiratory movements, as far as they regard the motion of the nostril, are opposite in paralysis of the portio dura to that which they are in the normal state; for while in the normal state the nostrils are dilated during inspiration, and constricted during expiration, they become in facial palsy constricted during inspiration by the air rushing into the lungs, and dilated during expiration by the air being driven out from the lungs.

Paralysis of the muscles of the ear, which are animated by the facial nerve, does not betray itself by any symptoms, since the human ear is kept in its ordinary position by the rigidity of its cartilages. On the contrary, in animals the ears of which are soft and long, as is the case in the rabbit and the ass, the ears drop after section of the facial nerves.

By paralysis of the *zygomatici* muscles, and the *levator anguli oris*, the angle of the mouth appears depressed and pendant, and it is drawn towards the opposite side; the angle of the mouth of the sound side, on the contrary, appears higher, and is drawn towards the ear.

Paralysis of the *buccinator* muscle causes the cheek to appear very flaccid and hang loosely, whereby the face appears old. During inspiration the cheek becomes depressed, while during expiration it cannot resist the pressure of the air, and therefore becomes distended and swelled; thus a movement is produced the same as that

closed, so that no inspiration can take place through it. As horses breathe only through the nose, and not through the mouth, they die of asphyxia, if a section of both facial nerves has been made.

made in smoking a pipe. Mastication is generally not much impaired, since the temporal and the masseter muscles are not animated by the portio dura, but by the trigeminal nerve; but eating, nevertheless, becomes troublesome, as in consequence of the paralysis of the buccinator the food, after having been chewed, becomes accumulated between the jaw and the cheek, which latter is swelled by it; and not unfrequently the patient is obliged to use his hand for bringing the food under the teeth, and on drinking the fluid runs out at the corner of the mouth. The speech is likewise rendered somewhat difficult by the looseness of the cheek.

If the *orbicularis oris* is paralyzed, the patient is unable to purse up his mouth and to whistle, the lips are drawn to the opposite side and appear longer, the sulcus nasolabialis is more prominent, and an involuntary flow of saliva is observed. Besides, the pronunciation of the labials is rendered very difficult.

Such are the symptoms if the superficial branches of the facial nerve are paralyzed; if the facial nerve is injured in its intra-cranial portion, other symptoms are generally connected with those related before; viz. loss of taste with a feeling of numbness in the tongue, caused by paralysis of the *chorda tympani;* difficulty of deglutition, by paralysis of those branches of the facial nerve which animate the muscles *digastricus* and *stylo-hyoideus;* deviation of the uvula, and the hearing is affected. In some cases it has been noticed that the patient was able to move the tongue, but not to such an extent as

to cover the upper lip by it. Deep-seated palsies of the portio dura are produced by inflammation of the sheath of the facial nerve, by fracture, caries or necrosis of the petrous portion of the temporal bone, and are often associated with otitis; but they are scarcely ever a symptom of primary brain disease. The brain, however, may afterwards become affected, if the disease extends from the temporal bone to the meninges and the medullary substance. In all cases which result from injury to the trunk of the portio dura, benefit can only be expected from an electric treatment, when the original lesion has nearly or totally subsided; if the continuity of the fibres of the facial nerve has been quite destroyed, the palsy is incurable. In some cases it happens that, after the paralysis has existed for a certain time, a permanent contraction of the paralyzed muscles takes place; it is evident that nothing can be expected from electricity in such instances. But when the nerve has regained its nomal condition, facial palsy is generally cured by a judicious faradic treatment, even if the case be of very long standing. Professor Oré has related a case of facial palsy of eight and a half years' duration, which was cured by electricity, and Dr. Russell Reynolds mentions a case of fourteen years' standing which was notably improved by electricity. It is, however, necessary to state that in advanced age the probability of the cure is less. If we wish to increase the chances of the success, it is necessary that the current should not be administered to the trunk of the portio dura, but to each muscle separately.

Paralytic affections of the tongue and the pharynx ought to excite our suspicion, as they are generally indicative of mischief in the brain. On the contrary, cases which occur of loss of power in the recurrent nerve are generally caused by hysteria, and seldom by structural diseases. In cases of this kind electricity frequently effects a cure.

3. *Hysterical aphonia.*

The first cure of hysterical aphonia by galvanism was effected as far back as 1800, when a German physician, Dr. Grapengiesser,* of Berlin, thought of trying the effect of the current of a single pair on the throat of a girl who had lost her voice for several years. He first vesicated each side of the larynx by blisters of the size of a shilling, and then applied the zinc pole to one of the excoriated spots, the silver pole to the other. The circuit was then kept up for a quarter of an hour, during which time the larynx heaved convulsively, and a great quantity of serous fluid flowed from the wounds. The sobbing continued after the metals had been removed, much mucus was expectorated, and two hours afterwards the voice was much more audible and clear. After this process had been repeated several times, the voice was perfectly restored. Six months afterwards, however, it was suddenly lost again in consequence of a cold, and it did not again return, although the same process of Galvanization was repeated. A similar case, in which the same thera-

* Versuche den Galvanismus zur Heilung einiger Krankheiten anzuwenden. Berlin, 1801.

peutical proceeding was adopted, has been recorded in the Dublin Quarterly Journal for February, 1847. In this instance the improvement began on the evening of the day when galvanism was first applied, and continued until the fourth day, when the voice was again lost. The process was then repeated, and the apparatus left on all night, with the effect of permanently restoring the voice.

Professor Sédillot* has published a case of complete dumbness and aphonia, which had existed for twelve years, in a woman thirty years of age. In this case the movements of the tongue were much impaired, the organ being retracted and directed upwards, and the patient not being able to bring the apex of the tongue in contact with the teeth. Professor Sédillot ordered the application of induction currents; one pole was placed alternately on different parts of the tongue, the other on the mastoid process, the posterior and superior part of the neck, and various points of the face. Some pain was experienced, and a severe head-ache followed this application. A week afterwards a second *séance* was held, after which the patient began to talk distinctly, though the voice had not as yet quite returned. A few more applications effected a complete cure.

Duchenne† has published two cases of hysterical aphonia, one of six months' the other of more than two years' standing; both cases were cured by the application of induction currents to the larynx. Duchenne also adds

* The Lancet. May 10, 1856.

† De l'électrisation localisée, etc., p. 774.

that he has been unsuccessful in other cases, but he does not give the proportion of successes and failures.

I have had ample opportunity of trying the value of galvanism in the treatment of hysterical aphonia, as I have been fortunate enough to see fifteen cases of this comparatively rare disease. For most of them I am obliged to the Physicians of the Samaritan Free Hospital. All the patients were women, and most of them under 30 years of age; two were married, thirteen single. In no case were there signs of such a morbid state either of inflammation, or of ulceration of the mucous membrane of the larynx, as would have accounted for the loss of voice; but the affection consisted merely in loss of power in the nerves and muscles of the larynx. In a case which was sent to me by Dr. Henry G. Wright, the merely paralytic character of the complaint might have possibly been mistaken, as that patient also suffered from venereal disease: a specific eruption over the skin, and a large node over the right eyebrow; so that by a superficial examination one might have been led to the diagnosis of aphonia resulting from syphilitic ulceration of the larynx. But the other signs of such an ulceration were not present, and that there really were none, became evident by the beneficial influence of a few applications of electricity. I may also mention that this case was the only one in which the cause of the complaint was quite evident, as it arose from over-exertion of the voice. In some of the other cases there was a thickening of the mucous membrane of the larynx, but not so much as would account for the loss

of voice. Some patients stated a cold draught to have been the cause of the loss of the voice; others did not know how it was brought on, as, awaking in the morning, they found the voice gone.

The degree of the affection was different. The normal "timbre" of the voice was totally lost in all cases, but most of the patients were able to whisper by movements of the lips and tongue. Such whispering was quite distinct in some patients, but hardly intelligible in others, two of which were observed in King's College Hospital, under the care of Dr. Todd, another in the Samaritan Free Hospital, under the care of Dr. Savage. A sore feeling in the throat was complained of by all the patients; four of them also felt pain in the chest, and in the epigastrium. Three were irregular as to the time of entrance of the catamenia; but amenorrhœa was not present in any of them. In two cases aphonia was only one symptom of a deep hysterical disturbance of the whole nervous system, as these patients suffered besides from globus hystericus, violent head-ache, sleepiness, cramps, and weakness in the limbs; one of them afterwards passed into a cataleptic state.

To give galvanism a fair trial, in most of these cases either indifferent drugs or no medicine was given. In all of them I applied a mild induced current, by means of moistened conductors, and directed the electrodes partially to the recurrent nerve, and partially to the tissue of the cricothyroid muscle, which, as Longet's experiments have proved, plays a prominent part in the formation of

the voice. This mode of application proved beneficial, as out of fifteen cases eleven were cured in a very short time. Faradization proved unsuccessful in four cases, which were of long standing, and complicated with other symptoms of hysteria. In eleven uncomplicated cases of comparatively short standing—as none of them extended beyond the period of four months—the treatment had the following result. In one of them the voice returned about three hours after the first application of a few minutes' duration. Two cases were cured by three, eight others by four, applications. In six cases the voice when it came back was at once quite as strong as it had ever been before; in five patients, on the contrary, an evident increase in the sonority of the voice was discernible from the beginning to the end of the treatment.

Probably it will be objected that not unfrequently in cases of this kind the voice suddenly comes back without any treatment whatever having been instituted against the complaint,* and that therefore it remains doubtful if electricity has been really of any use in it, but I hardly think it possible to deny the beneficial influence of Faradization in cases of this kind. Even if the matter were considered only theoretically, galvanism would give a very fair chance of recovery to a merely local paralysis not connected with any structural disease. Besides, the cases I have treated had existed without any change whatever for a longer or shorter space of time, and were only cured as

* An interesting case of this kind is related by Dr. Todd, in his clinical lectures on paralysis, etc., p. 265.

soon as placed under the influence of Faradization. I am also inclined to consider the circumstance of the gradual increase of the sonority of the voice, which was observed in five cases during the course of the treatment, as a proof of its efficacy.

As far as I have been able to ascertain, in one case of the eleven a relapse took place a fortnight after the voice had come back; two further applications then again produced the desired effect. I hardly think that there were any other relapses; because it is very likely that, if such had been the case, the patients would have again sought help for a very troublesome and annoying affection, from which they had been delivered by a short treatment not connected with any inconvenience.

4. *Local palsies of the extremities.*

Palsies of certain muscles, or sets of muscles, of the extremities are of frequent occurrence, and are generally caused by lesions of the motor nerves, by hysteria, by rheumatism, by lead-poisoning, or by diseases of the urinary organs; in certain cases, however, the cause of the affection cannot be ascertained. In most instances of local palsies of the extremities a well-conducted faradic treatment is of the most essential use.

a. Traumatic paralysis.

Structural lesions of the motor and mixed nerves are accompanied by paralytic affections of the muscles which are animated by the injured nerves. Paralysis of certain muscles of the fore-arm has been caused by surgical ope-

rations unskilfully performed, in which the trunk of the ulnar nerve was divided. Bandages improperly applied have produced paralysis, by pressure on certain plexuses of nerves. In persons who sleep very deeply under the influence of intoxicating liquors, paralysis of the arm has been caused during sleep by pressure of the head on the brachial plexus. By an acute or chronic inflammation of the sheath of a nerve the nervous matter may be entirely destroyed, and also tumours may give rise to paralysis by compressing the substance of the nerves.

In consequence of such and other lesions of the nerves the voluntary movements, the sensibility, and the excitability of the muscles to the electric stimulus are more or less impaired, the degree of functional disturbances being directly proportional to the extent of the lesion. If all the fibres of a nerve are destroyed, the properties of the muscles are totally lost. Cases of this kind are incurable, unless a regeneration of nervous matter takes place. It is beyond doubt that in certain cases nerves, which have been divided and have undergone a more or less considerable loss of substance, may be regenerated; and it is proved by microscopic observations of Messrs. Follin, Brown-Séquard, and others, that in cases of this kind there is no interruption of the continuity of the nervous fibrils throughout the cicatrix. If such regeneration of nervous matter has taken place, and the nerves and muscles still remain paralyzed, the electric current is the most efficacious means for restoring their lost vitality.

In other cases, where the continuity of the nervous

fibres has only been more or less damaged, but not entirely destroyed, there may be loss of power in the muscles, and diminution of their sensibility and excitability to the electric stimulus. Cases of this kind are more amenable to electricity than such in which the properties of nerves and muscles have been entirely destroyed. Duchenne asserts, that a certain amount of hyperæsthesia, which manifests itself in cases of this kind after the first few applications of electricity, is a favourable sign, as it indicates the commencing return of muscular nutrition. In all such cases electricity should be locally applied to the muscles, the current should be somewhat intense and very rapidly interrupted.

b. Hysterical paralysis.

In this kind of paralysis neither the nervous centres nor the motor nerves are diseased, although the symptoms may closely resemble those caused by diseases of the brain of the spinal cord. It occurs in hysterical women, and is brought on either suddenly by anxiety, fright, or excitement, or it creeps on gradually and unawares. Generally the muscles of the lower extremities, and especially the recti of the thighs, are paralyzed (hysterical paraplegia,) or the muscles of the arm and leg on the same side may be affected (hysterical hemiplegia,) or only a single muscle or set of muscles of one limb may suffer. Hysterical paralysis is seldom the only symptom of hysteria in a patient, but it is generally accompanied by globus, hysterical pains, cramps, and disturbances of the men-

strual function. Often nothing is apparently more whimsical than the course and the termination of hysterical paralysis. Certain cases get well in a very short time without any medical treatment, others resist for years a variety of energetical therapeutical experiments. In a great number of cases the faradic treatment has yielded splendid results; although it is by no means infallible. As to the mode of application, I may mention, the current should be locally applied to the paralyzed muscles, and if this should fail to effect a cure, Faradization of the skin may be resorted to.

c. *Rheumatic paralysis.*

As facial palsy is often caused by a draught of cold air, thus paralysis of the muscles of the extremities is not unfrequently induced by rheumatism. The angler, the huntsman, and others who by pleasure or necessity are much exposed to the changes of temperature, are liable to this kind of palsy, which affects with preference the muscles of the lower extremity, thus giving rise to paraplegia, which is frequently mistaken for a symptom of a disease of the spinal cord. The extensor muscles of the fore-arm, which are animated by the radial nerve, are also often subjected to rheumatic paralysis. Next in frequency ranks paralysis of the deltoid and trapezius, in consequence of which the elevation of the arm becomes difficult or impossible. Finally, the interossei and lumbricales muscles are liable to rheumatic palsy. I have often observed this affection in young ladies, where the first symptom is generally a feeling of numbness in the

fingers, and the movement becomes difficult and tiresome. On faradizing the interossei their excitability generally appears impaired. In such cases it is very easy to arrest the disease by a short faradic treatment; if nothing be done against the affection, the muscles may in time become atrophied; the interosseous spaces appear hollow, the circulation becomes impaired, the hand thin and cold, the fingers can be but slightly removed from each other, and the extension of the last two phalanges is impossible; the numbness and stiffness increase, and at last the hand becomes quite useless.

The invasion of rheumatic paralysis is sometimes sudden, in other cases gradual. It may begin with pain in a set of muscles, whereby motion is rendered difficult or impossible; and when the pain has vanished, the immobility still continues; in other cases no pain, but only numbness, is experienced, which is especially great in the toes, if the seat of the paralysis is in the lower extremities. If the invasion has been sudden, and pain is felt in the paralyzed muscles, the electric excitation of the muscles also produces much pain; but when the disease has come on gradually galvanism excites very little sensation.

There is no kind of paralysis in which the therapeutical effects of electricity are so striking as in rheumatic paralysis, in which affection it cannot be replaced by any other remedy. This applies also to protracted and severe cases which have resisted a variety of energetical treatment. Thus M. Guitard has related the case of a patient who had suffered for three years from rheumatic paraly-

sis; there was general emaciation and immobility; the head was inclined to the chest, the thighs flexed upon the abdomen, the legs upon the thighs. Faradization was now practised for a month, and after that time the head could be held erect, and the legs be moved into and out of bed. The faradic treatment was then discontinued for some time, whereupon the patient relapsed into nearly his previous state; it was then recommenced, and at the end of six weeks an almost total recovery had taken place.

I have had ten cases of rheumatic paralysis of the muscles under my care, two cases of paraplegia, two cases of paralysis of the extensors of the fore-arm, five cases of palsy of the interossei, one of paralysis of the deltoid and trapezius. In all these cases the patients derived a very marked benefit from the faradic treatment, and most of them were quite cured. I am quite satisfied, that every case of rheumatic paralysis can be cured by electricity, provided that the muscular tissue has not yet been atrophied, and the patients do not discontinue the treatment too soon.

Even in cases of muscular atrophy resulting from rheumatic paralysis, electricity is of great service.

d. Lead-palsy.

Painters and compositors are most liable to this disease; in the former the blood is poisoned by inhalation of small particles of the powder with which paint is made; or the poison is absorbed through the skin. In the latter

the disease is produced by handling printers' types. Not unfrequently lead is taken with adulterated wine or beer; thus lead-palsy often occurs in travellers for wine-merchants; the poison may also get into the blood with the water which has passed through leaden tubes, or with snuff which has been packed in lead-foil. If the blood has become contaminated with lead, various disturbances in the system are produced; such as colics, cramps, amaurosis, neuralgia, paralysis. Paralysis attacks with preference the upper extremities; thus M. Tanquerel des Planches saw amongst 113 cases of lead-palsy, 93 cases of palsy of the arms, 14 of the lower extremities, and 6 of general paralysis. Certain sets of muscles are more liable to this kind of palsy than others. The extensors of the right fore-arm are most liable to it; therefore the wrist drops and cannot be extended; the power of extension of the first phalanges of the fingers is also gone; but the motion of the last two phalanges is not impaired, as the interossei scarcely, if ever, suffer from lead palsy. The muscles generally soon undergo atrophy, the back of the fore-arm appears concave, the thenar eminence flattened, and the triceps and deltoid may also become more or less wasted. The electric contractility of these muscles is either totally gone, or considerably diminished; but the sensibility is generally preserved. Electricity is the most efficacious remedy for lead-palsy, and should always be resorted to in cases of this kind; it is even useful if the bulk of the muscles is considerably diminished, and if the muscles do not respond to the faradic stimulus.

e. Paraplegia arising from diseases of the urinary organs.

Incomplete paralysis of the lower extremities, arising from diseases of the urinary organs, has lately been described by M. Leroy d'Etiolles and Mr. Spencer Wells. The diseases which cause this form of paralysis, are nephritis, abscesses in the kidney, renal calculus, inflammation, and ulceration of the mucous membrane of the bladder, enlargement of the prostate, stricture of the urethra, &c. In such cases the discharge of the urine is more or less impeded; the sphincter ani is also weak, the digestion deranged, the limbs very weak, and the muscular sense nearly lost. The degree of the weakness in the legs varies with the state of the urinary organs. Generally the paraplegia disappears soon after the impediment to the discharge of the urine is removed; but if the paralysis still exists after the removal of its cause, a faradic treatment is of the most essential use.

5. *Wasting palsy* (*Cruveilhier's atrophy.*)

This formidable disease, on which we have lately received an able essay by Dr. Roberts, is mainly produced by malnutrition of the muscles, which are progressively destroyed, while the nervous system may be quite healthy, or is only secondarily affected. The disease does not equally attack all the muscles united to a set, but falls apparently capriciously on this or that individual bundle of muscles. Such muscles generally appear of a pale yellow; they are more or less wasted, and often reduced to thin cords. Fat, which is always produced in the re-

trogressive metamorphosis of tissues, may become accumulated, and take the place of the muscular fibres; in such cases the emaciation is not remarkable, and the limbs may even appear more bulky than formerly; in other instances the fat is eliminated as soon as formed, and then the limbs are shrunk to the last degree. When the sarcolemma has been destroyed, and the sarcous elements become converted into fat and granular matter, the last ramifications of the motor nerves generally become affected in their turn; in some instances this affection spreads to the anterior roots of the spinal nerves, and even atrophy of the cord may finally be the consequence; but this is never the cause, but only the consequence, of the primary affection of muscular tissue.

The disease mostly affects adult males; but females and infants are not spared. It generally arises from overwork, or anything that over-fatigues the muscles; also from exposure to cold, or from contusions; in some instances there is an hereditary taint, and several members of the same family are affected; while in a great number of cases no palpable cause of the complaint can be ascertained. The disease is almost invariably of slow invasion, and is only discovered by the feeling of loss of power, which is experienced after a great deal of injury has already been done. The loss of power is quite proportional to the degree of atrophy in the muscles. When by the loss of power the patient's attention is drawn to the state of the muscles, he discovers that they are wasted. Besides, rapid quiverings of the individual muscular bun-

dles are perceived, which are never painful, and do not occasion motion in the limb. These quiverings do not accompany all cases of wasting palsy; but if observed, they indicate that the disease is advancing; if they cease, the disease is arrested, or the muscle has become totally destroyed. Many patients also complain of real cramps, which are distinct from these quiverings, and which occur especially during the night in the abductors of the thighs, so that the legs are shaken towards each other, and the patient is prevented from sleep.

There are two forms of this disease, the *partial* and the *general* form. The general form begins either in the upper or in the lower extremities, and as it almost always spreads to the trunk, threatens life. The partial form is not necessarily fatal, but it may pass into the general form, and thus ultimately cause death; it begins either in the hand or in the shoulder, generally of the right side, and may destroy many muscles of the upper extremity, while in the general form all the voluntary muscles throughout the body may be affected by it, with the exception only of the muscles of the eyeball and the muscles of mastication.

If the disease begins in the hand, the muscles of the thumb are generally the first affected; the thenar eminence becomes replaced by a flattened hollow space between the first and second metacarpal bones; afterwards the interossei and lumbricales and the hypothenar eminence become affected. From the hand the disease spreads to the fore-arm; the extensors of the fore-arm

are especially liable to this affection, so that the fingers are generally slightly bent, but the flexor muscles may also be destroyed, and in this case the last two phalanges cannot be bent, so that the patient is unable to grasp or seize any thing with the hand.

In other instances wasting palsy first invades the muscles of the shoulder, and attacks with preference the trapezius, the serratus magnus, the rhomboidei, and other muscles which unite the scapula to the trunk; the scapula is consequently displaced and twisted around its axis; its upper angle is depressed by the weight of the arm, while the lower angle is raised and projects one or two inches from the surface of the thorax. From the shoulder the disease spreads towards the arm, destroying the deltoid and biceps; thereby the acromion and the coracoid process become prominent under the skin, and serious functional disturbances are the necessary consequence. Although the patient generally learns in the course of time to manœuvre very cleverly so as to compel muscles which have escaped destruction to do the work of such which have been wasted, he is at last no longer able to raise his arm nor to bend the elbow-joint; he can no longer dress and feed himself; he experiences considerable difficulty in putting on his hat or drawing a handkerchief from his pocket.

If the muscles of the lower extremities are attacked, walking becomes difficult; and at last motion becomes quite impossible. The muscles of the chest, chiefly the pectoralis major, become affected in their turn; the chest appears shrunk, especially beneath the collar-bones.

A certain sign that the disease will shortly prove fatal is destruction of the facial muscles; the physiognomy loses all expression; the saliva is sometimes seen to flow involuntarily; the laryngeal muscles are likewise affected, articulation becomes slow and difficult; the muscles of deglutition, and at last the diaphragm, is attacked. This generally closes the scene; the slightest impediment to respiration which may supervene, produces asphyxia.

It is exclusively the voluntary striped muscles which are thus destroyed; all other organs are generally in the best possible condition. There is no gastric derangement, and the intelligence remains undisturbed to the last moment. There is no anæsthesia of the skin; but the patients are often sensitive to cold, and complain of pain or numbness in the limbs.

The disease may thus end in death; but in some instances it is arrested and even recovery may take place. Recent cases are more likely to recover than such as are of long standing.

In this affection the localized application of induction currents to the muscles is the only means by which we may hope to arrest the progress of atrophy, and to improve the condition of the patient. In causing the muscles to contract individually, more blood is attracted to their tissue, the bulk and heat of the muscles is increased, and this greater afflux of blood affords the possibility of regeneration. But if this result is to be accomplished, the treatment must be persevered in for a long time, even if no palpable amelioration should occur after the first few

weeks. That certain cases, especially such as are of the general form, may run their fatal course in spite of a faradic treatment, is no disparagement of the remedy, which cannot be expected to accomplish impossibilities.

C. *Paralytic conditions of organs animated by sympathetic fibres.*

1. *Intestinal atony.*

In cases of *constipation* which are caused by a want of peristaltic motion of the contractile fibre-cells of the intestines, and by loss of power in the abdominal muscles, electricity may be very useful, especially if the affection occurs after protracted diarrhœa and the abuse of aperient medicines. In such cases a total abstinence of laxative medicines is generally imperative, and even simple enemata sometimes do mischief; on the contrary, by galvanism powerful peristaltic movements of the intestines may be induced, without injuring in any way the mucous membrane of the alimentary canal. Cases of habitual constipation, which had resisted all previous treatment and were rapidly cured by electricity, have been described by Dr. William Cumming,* of Edinburgh, and Dr. Clemens,† of Frankfort. I have had a case under my care in which two drops of croton-oil failed to induce opening of the bowels, and in which by the application of induction currents a ready discharge of the fæces was brought about.

* On the use of electro-galvanism in a peculiar affection of the bowels. London Med. Gaz. vol. ix. p. 969.

† Die angewandte Heil-Elektricität, Deutsche Klinik, 1858.

Tympanitic distention of the abdomen is also often the consequence of intestinal atony, and of loss of power in the abdominal muscles; the intestines meet with no resistance to their distention, and often an enormous meteorism is produced. This is frequently observed in hysterical women; also after the partaking of indigestible food; in acute diseases, especially typhus, pneumonia, small-pox, puerperal fever, peritonitis, etc. This tympanitic distention not unfrequently threatens life, as it may produce asphyxia by paralysis of the diaphragm, and compression of the lungs. In tympanites occurring in acute diseases, the application of electricity does not appear justifiable; but if it occurs in hysterical women, and after the indigestion of indigestible food, a trial of faradic treatment is allowable. Different modes of application have been resorted to. M. Becquerel affirms that he has tried the effect of the induced current in many cases of this kind; he placed the positive electrode into the mouth, and the negative into the rectum; and has never seen any benefit derived from it. The method adopted by M. Becquerel is therefore not to be employed, as it is both inconvenient and useless. Dr. Cumming has proposed placing one electrode on the spine, and the other on the abdominal parietes. I generally place both electrodes on different points of the abdominal parietes, and keep up the action of a rather strong current for about ten minutes. As to the position of the poles, it appears to me best to have the current guided in the direction towards the anus.

2. *Paralysis of the bladder.*

It is beyond doubt that certain cases of paralysis of the bladder can be cured by the application of electricity. This affection arises frequently from disease of the brain or of the spinal cord; in such cases the application of electricity cannot have any permanent beneficial effect. In other instances, however, it comes on slowly without any apparent cause. In Graves' Clinical Medicine, a case is related of a patient of 70 years of age, in which the application of electricity was crowned with success. Drs. Goodwin and Radford have cured a case of paralysis of the bladder, which had come on in a lady after labour, by one application of galvanism. Dr. Frazer has reported a case which was caused by over-distention of the muscular fibres of the bladder, in consequence of retention of the urine, which resulted from exposure to cold and damp, in a patient aged 60 years. In this instance electricity proved successful after the failure of ergot of rye, and other remedies. Dr. Russell Reynolds has also successfully treated a case of paralysis of the bladder, by induction currents. As to the mode of application, we may either localize the electric current in the tissue of the bladder by introducing the double sound, which has been described p. 232, or we may introduce a catheter into the bladder, and close the circuit by placing a female catheter connected with one of the poles into the rectum, or by placing a moistened excitor to the spine.

3. *Amenorrhœa.*

The opinions of medical electricians on the therapeutical value of electricity in amenorrhœa differ widely from each other. Thus, Dr. Golding Bird* asserts that electricity is the only really direct emmenagogue we possess, and that it always excites menstruation where the uterus is capable of performing this function. On the other hand, M. Becquerel† contends that he has very often, and for a very long time, applied electricity, and that he has never seen any effect; that in a case of a young woman to whom electricity was applied for neuralgia during the time of her catamenia, the menstrual function was suppressed by the application of electricity, and that he is entirely adverse to the employment of electricity in amenorrhœa.

Such being the state of the question, we must look for well-established facts to arrive at a conclusion. Indisputable facts, however, confirm that electricity, and even every form of electricity, has an almost specific influence upon the vasomotor nerves of the ovaries and the uterus, when they are in a torpid state. Dr. Bird has cured 20 cases out of 24 cases of amenorrhœa, by the application of static electricity. The mode in which he applied it was to transmit a dozen shocks from an electric jar holding about a pint, through the pelvis, one conductor being placed over the lumbo-sacral region, the other just above

* Lectures on Electricity and Galvanism in their physiological and therapeutical relations. London Medical Gazette, 1847, p. 705.

† Traité des applications de l'électricité, etc. Paris, 1857, p. 286.

the pubes. Cases of amenorrhœa cured by the application of the continuous current have been recorded by Drs. Westring and de Molle. The induced current has proved beneficial in the hands of Duchenne, Schulz, Baierlacher, and my own. Even a lightning stroke has, according to Dr. Le Conte,* brought back the menstrual function in a woman of at least 70 years of age, in a plantation in Georgia: in this woman the period had ceased for more than twenty years; but after she had been struck by lightning, the menses were completely re-established, and continued with the utmost regularity for more than a year after the accident; at the same time the mammæ had become enlarged.

Electricity is especially valuable as an emmenagogue in young women, where the menstrual function has not yet been fully established in consequence of a torpid state of the vasomotor nerves of the ovaries and the uterus. On the contrary, if amenorrhœa is caused by structural diseases of the ovaries and the uterus, there is no reason for the administration of electricity.

I have made many experiments in order to find out the most effectual way of administering electricity in amenorrhœa. Duchenne has recommended localizing the electric current in the tissue of the uterus; I have tried this proceeding in one case, in which it answered perfectly; but few patients are likely to admit of this operation. Subsequent experience has led me to the conviction that in many cases the menses are caused to appear,

* New York Journal of Medicine, 1844.

whatever may be the part of the body which has been faradized; but that the most effectual way is to apply the electrodes to the abdominal parietes. It has frequently happened in cases under my care that the catamenia appeared after one or a few séances, when the faradic treatment was directed against another complaint. In a lady who was under the care of Mr. Spencer Wells, and who suffered from aphonia, I guided a mild current along the course of the recurrent nerve; after the first séance the catamenia appeared. In another lady I was requested to faradize the drum of the ear for nervous deafness and noises in the ear; after the first séance I was informed that the patient soon after the operation had felt a sensation throughout her body generally, and the catamenia, which had before been behind the due time, had appeared a week too soon. I have observed the same in a lady whom I treated for hysterical paraplegia; in another, who suffered from pain in the back, etc. In cases of real amenorrhœa, however, the application to the abdominal parietes is, as I have already stated, the most efficacious method of treatment. I am ready to admit that electricity is not infallible in cases of amenorrhœa without morbid changes in the ovaries and the uterus; but I am quite satisfied that it is one of the most valuable remedies in this affection which are at our disposal. If M. Becquerel has never seen any success from the faradic treatment of amenorrhœa, he has been very unfortunate in the selection of the cases, or in his method of applying electricity.

D. *Stoppage of lacteal secretion.*

In consequence of emotion, fright, etc., sometimes the lacteal secretion is diminished, or entirely stopped in one or both mammæ. The application of induction currents to the mammæ by means of moistened excitors has caused the milk to re-appear in cases observed by Messrs. Aubert and Becquerel. A few applications of a duration of about a quarter of an hour each have been sufficient to attain the result.

II. *Treatment of spasmodic diseases and contractions by electricity.*

Spasmodic diseases are much less amenable to electricity than paralytic affections; since they generally arise from irritative lesions of the nervous centres. If the convulsions are merely local, electricity deserves a trial, and can be employed in three different ways. The most rational method seems to be by sending a constant continuous current of a certain intensity through the affected muscles, as by such a proceeding we are able to tranquillize an irritated state of a nerve; especially if the direction of the current be inverse. Duchenne has recommended the application of induction currents to the antagonists of the muscles spasmodically affected, and affirms that he used this means with success in cases of wry-neck. Finally, electricity of high tension can be administered as a counter-irritant to the skin, a method which has been successfully applied especially in cases of chorea. In the opinion of Dr. Remak, all sorts of contractions, especially

those which are caused by irritative diseases of the nervous centres, can be cured by the application of the continuous current. He states that in such cases the current does not act on the nerves to which it is applied, but on the nervous centres, which would then act in their turn upon the contracted muscles; and that the result is that after a few minutes' Galvanization the muscles previously contracted are relaxed and rendered amenable to the influence of volition. Time will show if these assertions are correct.

I do not intend repeating here the reports on the cure of cerebral convulsions, epilepsy, catalepsy, etc., by electricity, which have frequently been published, but shall confine myself to consider the therapeutical value of electricity in chorea, writer's cramp, spasmodic wry-neck, tetanus, and hysterical cramps and contractions.

1. *Chorea.*

This affection, which is generally brought on by terror, fright, rheumatism, or intestinal derangement, is frequently seen to disappear under the influence of cold affusions to the spine, strychnia, carbonate of iron, iodide of iron, iodide of potassium, etc.; many cases get well without any medical treatment. Labaume, Fabré-Palaprat, Drs. Addison, Golding Bird, and Gull, have treated cases of chorea by electricity, and have been satisfied with the result. Dr. Bird has reported 37 cases, 30 of which were completely cured, five relieved, one refused to continue the treatment, and only one was not cured.

He applied electricity of high tension as a counter-irritant to the skin, by drawing sparks from the spine (p. 201,) and affirms that the rapidity with which the patients were relieved, was nearly proportionate to the facility with which the peculiar papular eruption on the skin took place. Dr. Gull, who has also seen good effects from the electric treatment of such cases, supposes that the benefit is the result of a direct stimulus to the blood-vessels of the nervous centres (?), producing a more tonic and vigorous circulation in them.

I have had only one case of chorea under my care, a girl of 16, who was kindly sent to me by Dr. Henry G. Wright; the disease was much ameliorated by a few applications of galvanism, but as she then ceased to attend I cannot say if she was quite cured. The best treatment appears to be to send an inverse constant continuous current (of six or eight pairs of Daniell's battery) along the course of the affected nerves.

2. *Writer's cramp.*

This peculiar affection may be caused by emotion and anxiety, by rheumatism, by over-exertion, and by wounds of the radial or ulnar nerves of the right hand. Some cases of writer's cramp are really spasmodic; the fingers, and especially the thumb, being strongly flexed into the palm of the hand whenever the patient attempts to write; in other cases it is a paralysis of the short extensor of the thumb, the adductor of the thumb, and the abductor of the fore-finger; the hand cannot hold the pen steadily,

and the fingers slip away from it. If the disease is spasmodic, a constant continuous current should be applied to the flexor muscles; but if it is caused by loss of power, a faradic treatment should be resorted to. In five cases which I have had under my care, the affection consisted of loss of power, and three of them were completely cured by Faradization; in the remaining two cases amelioration was produced, and a cure would have been probably effected if the patients had not discontinued the treatment too soon. As generally all other means fail to effect a cure in this troublesome affection, a trial of electricity cannot be too strongly recommended in it.

3. *Spasmodic wry-neck.*

Spasmodic wry-neck occurs mostly in adults, and can therefore scarcely be considered as a form of chorea. It consists of a convulsive affection of the spinal accessory nerve of one side, whereby the sterno-cleido-mastoid and the trapezius muscles are thrown in commotion. Electricity of high tension as a counter-irritant, and induction currents methodically applied to the antagonists of the suffering muscles, have effected amelioration or cure. The continuous current has not yet been applied in this affection, but I am inclined to consider it as the most efficacious remedy for it.

4. *Tetanus.*

Many cases of tetanus cured by electricity have been published, but such observations have not been given with sufficient detail. It is obvious that if electricity is used

in this formidable disease, only the continuous current should be employed. Matteucci has recommended galvanizing the spinal cord by an inverse continuous current, the positive pole being placed at the sacrum, and the negative to the occiput. To this Du Bois Reymond has objected that the current will not penetrate to the cord, which is surrounded by very imperfect conductors of electricity, unless the intensity of the current be very high. But even conceded that we cannot act directly upon the spinal cord, it may be safely recommended to apply the current of about ten pairs of Daniell's battery to the muscles spasmodically affected; with the exception, however, of the muscles of the jaw, as galvanization of them would probably cause over-excitation of the retina.

5. *Hysterical cramps and contractions.*

In these affections neither the nervous centres nor the motor nerves and muscles are palpably injured; and it may therefore be hoped that electricity can be of service in them. Dr. Byrne, Dr. Meyer, and M. Becquerel, have published cases of this kind, which were either cured or considerably ameliorated by the application of electricity. Dr. Byrne has not mentioned the form of electricity he employed; Dr. Meyer and M. Becquerel have used induction currents of rather high tension, which were applied from about ten to fifteen minutes each time.

III. *Treatment of anæsthesia by electricity.*

Anæsthesia may be caused by diseases of the nervous centres and of the sentient nerves; in such cases the elec-

tric current can be of use only after the original lesion has subsided. The chances of success are greater, if anæsthesia is idiopathic, rheumatic, of hysterical origin, or produced by poisoning.

1. *Loss of Smell.*

Loss of smell is often to be traced to morbid changes affecting the olfactory nerve, which may be compressed by exostosis, tumours, etc. I have seen a case in which the loss of smell evidently arose from over-excitation of the olfactory nerve, as the patient had for many years been in the habit of taking more than an ounce of the very strongest snuff every day, and the smell had very gradually disappeared. This might have been a good case for an electric treatment, which I proposed to the patient, but he would not submit to it.

2. *Amaurosis.*

Amaurosis has been often treated by galvanism, and M. Magendie has been fortunate enough to cure cases of this kind. It is obvious that we can only hope to succeed, if the amaurosis is not caused by disease of the brain, or of the organ of vision, or if it is the result of Bright's disease and diabetes. As the continuous current has a special action on the retina, this form of electricity should be used (a current of about six pairs of Daniell's battery;) the employment of induction currents is also allowable, and in this case the magneto-electric current best answers the purpose. Moistened electrodes may be applied to any part of the face, as the action on the retina

takes place by reflex from the trigeminal to the optic nerve. It is quite unnecessary to employ electro-puncture, which generally frightens the patients, and is connected with many inconveniences. The séances should be very short and often repeated. An examination of the eye by means of the ophthalmoscope should always precede the commencement of the galvanic treatment, as many cases which are said to be amaurosis really depend upon morbid changes in the retina, choroidea, etc., which absolutely prevent the possibility of vision.

3. *Nervous deafness.*

Nervous deafness has often been treated by electricity, and there can be no doubt that certain cases are amenable to it. It is especially that sort of deafness which occurs in hysterical women, and is connected with noise in the ear, which is liable to be beneficially affected by galvanism. I have had twenty-three cases of deafness under my care, and have been assured by fourteen patients that they heard very much better after having been faradized for a certain time. In one case I have been fortunate enough to stop the noises in the ear entirely, while in nine cases no benefit was afforded. The application of electricity in cases where we cannot discover any structural disease of the ear seems justifiable, but as long as the diagnosis of the diseases of the ear remains as doubtful as it is at present, the chances of failure seem to be just as great as those of success.

4. *Loss of taste.*

In *loss of taste* the continuous current is probably more efficacious than induction currents, which act only on the sentient nerves of the tongue, but not on the gustatory nerves.

5. *Hysterical anæsthesia.*

Hysterical women often complain of a *sensation of numbness*, which is sometimes fixed in a limb, or part of a limb, in other instances wanders about the body. Cases of this kind are generally speedily cured by electricity. Thus I may mention the case of a woman, aged thirty-six, who was sent to me by Dr. Henry G. Wright; she complained of a sensation of numbness, especially in the nape of the neck, and the dorsal region of the spine; and also in both arms. I applied a mild induced current to the parts mentioned, and when I saw the patient the following day, she stated that she had nearly regained the normal feeling in them; three other séances effected a complete cure. In other instances, however, a longer treatment may be required.

10. *Case of hysterical anæsthesia and paraplegia.*

Ann C., aged twenty-eight, married, Carlisle Ward, St. Mary's Hospital, under the care of Dr. Alderson. Three years ago she suffered from rheumatism. Fifteen months ago the first symptoms of her present illness appeared; her walking became difficult, and she did not feel the ground, and a continual sensation of numbness in the back and the lower extremities was complained of. She has never suffered from cramps, or twitches in the

leg; she has always been regular. She has been treated by cuppings, leeches, and blisters all along the spine; strychnia, calomel, bandages, and galvanism. When I first saw her, July 5, 1857, the state of sensation was as follows: the skin of the face, the neck, and the arms, had preserved its normal sensibility; on the back there was anæsthesia, from the seventh cervical vertebra down to the sacrum; the prick of a pin is not felt at all in the middle line of the spine, nor on the lower extremities; her walking is staggering, and the muscles of the lower extremities respond very little to the electric stimulus. There are no disturbances in the function of the bladder and the rectum.

In order to restore the lost vitality to the sentient nerves, I applied a current of high tension by means of wires lodged in metallic cylinders to the skin of the back, and of the lower extremities. While in the normal state of the nerves the faradic stimulus is felt as soon as applied, this patient did not feel it until it had been applied from five to six seconds. Such was the case as well on the back as on the lower extremities; but on the soles of the feet no sensation was to be excited, even by a most intense current. I continued Faradization, and after six séances the sensation on the back had become nearly normal. The sentient nerves of the lower extremities were more deeply impaired than those of the back, and it took a longer time to produce an amelioration in them. The muscles became also much strengthened by the treatment. The patient walked much steadier when she left the Hospital, although she had not quite recovered.

6. *Anæsthesia by poisoning.*

If anæsthesia is caused by *poisoning* with chloroform, opium, or other narcotic substances, the electric stimulus is one of the most efficacious means of rousing patients from insensibility. Messrs. Jobert de Lamballe and Ducros have made many experiments on chickens, pigeons, and other animals, in which anæsthesia by ether or chloroform had been produced, and which were readily aroused by the application of electricity. Clinical experience has also proved the utility of galvanism in cases of this kind. In chloroform-poisoning the electric current can be directed by acupuncture needles to the right ventricle, as the right cavities of the heart are always distended with blood if animation is suspended by chloroform; and if the right ventricle is stimulated to contract, animation may be restored; or the current may be directed by metallic wires to the sentient nerves of the skin; or the phrenic nerve may be faradized in the way described above, in order to produce artificial respiration. Care must be taken, however, that the current administered should not be of very high tension, as by that means the weakened animation might be entirely destroyed.

IV. *Treatment of neuralgia by electricity.*

If neuralgia is caused by wounds of the nerves, by inflammation, hypertrophy, or cancer of the neurilemma, electricity cannot be expected to cure this affection; the same is the case if neuralgia originates in inflammation, caries, exostosis of the bony canals through which the

nerves pass, or in diseases of the nervous centres, or in morbid states in the liver, uterus, ovaries, kidneys, etc. But if the neuralgia appears to be merely a morbid exaltation of sensibility without structural changes, or if it is caused by rheumatism, the faradic treatment may be resorted to with a fair chance of success.

From the time when Sarlandière and Magendie first made known their observations on the therapeutical use of galvano-puncture, galvanism has been frequently and in various ways administered to relieve such neuralgic pains as defy other therapeutical proceedings. The practice of galvano-puncture being connected with more or less inconvenience, viz. in many instances very violent pain during the operation, and afterwards inflammation and suppuration in those tissues into which the needles have been thrust, other modes of applying galvanism have therefore been naturally resorted to. Duchenne has recommended Faradization of the skin, by means of metallic brushes conveying a very powerful electro-magnetic current to the affected points, in order to produce a strong revulsion; but the pain produced by this proceeding is, according to Duchenne himself, atrocious, and in a certain number of cases the operation has not been successful. Another, and in my opinion the best, way is to send an induced current of medium intensity for a certain time through the affected nerve by means of moistened conductors, as I have shown that by such a proceeding a direct reduction of the sensibility in a nerve may be produced. The pain produced by it is insignificant and scarcely worth

mentioning, when compared to the often excruciating neuralgic pain against which the proceeding is resorted to. On the other hand, I have seen the method alluded to answering in cases where both electro-puncture and Faradization of the skin had been practised with little or no success. From a number of patients I have treated for neuralgia two cases are subjoined to illustrate the therapeutical proceeding.

11. *Case of Tic Douloureux.*

Mrs. ——, aged twenty-eight, had been in good health until May, 1857, when, in consequence of having got wet through, she was seized by violent pains in the right side of the face, accompanied at first with fever and general indisposition. The latter symptoms soon subsided, but not the very violent shooting pain, which came on in paroxysms, at the end of which the patient was completely exhausted. For the first few weeks the paroxysms came on very irregularly, about four or five in the course of the day; but after some time, an intermittent character was remarked, as only one paroxysm came on every other day between four and five o'clock in the afternoon. Large doses of quinine and arsenic had been given, but without producing the anticipated effect; the patient had also been treated by calomel, sublimate, iodide of potassium, and blisters. Her general health has much suffered; she has become nervous and irritable. When I first saw her, the present state was as follows:—There are always premonitory symptoms which announce the approaching pa-

roxysm, viz. a sort of tickling in the epigastrium, followed by formication in the face. Then very violent pains begin, which are chiefly felt on the zygomatic bone, beneath the lower eyelid, in the cheek and chin, a little less on the nape of the neck, but not in the forehead and the temple. This paroxysm usually lasts about half an hour, and then slowly subsides into a dull pain, which continues for three or four hours. The following day she is free from pain, the third day is again marked by a paroxysm. On examination of the face, I found two of Valleix's painful points, viz. one on the zygomatic bone, where the temporo-malar, and another on the infra-orbitar foramen, where the infra-orbitar nerve emerges from the orbit; pressure on these two points excited a distinct painful sensation in the free interval. I therefore thought it well to place the poles alternately on these two points, by means of moistened conductors, conveying a rapidly interrupted induced current to the suffering nerves. The first application (Oct. 10, 1857) made at the time when the paroxysm had just commenced, alleviated, according to the patient, the severity of the pain, but did not shorten the duration of the paroxysm. On the 12th of October, another paroxysm came on at due time, and was then positively shortened by the application of induction currents. On the 14th premonitory symptoms, as usual, but no paroxysm. On the 16th a paroxysm came on which was subdued in five minutes. Five other faradic séances were held, the last paroxysm having been on the 26th of October. I saw the patient in the beginning of June, 1858,

when she told me that up to that time she had not been troubled again by the pain.

12. *Case of Sciatica.*

J. F. T., Esq., aged 35, from Edinburgh, has never been in strong health, and has suffered for a long time from acidity in the stomach. Eight years ago he had his left thigh amputated for tumor albus; he carries now an artificial leg, which, being very heavy, exerts a great strain upon the left side of the pelvis. Three years ago he first began to feel pain on the back of the right thigh, and on the inside of the leg, down to the ankle. The pain having been dull and heavy for some time, soon became keen and acute, so that the patient was laid up by it. He thought that it was brought on by his having taken too much exercise. He did not suffer from violent paroxysms of pain, followed by free intervals, but was permanently troubled. He placed himself under the care of two of the most eminent practitioners of Edinburgh, and after some time was much relieved, the acuteness of the pain slowly but gradually subsiding. He then left Edinburgh; but being still troubled, he had acupuncture practised upon him, needles being thrust into the sciatic nerve. From this proceeding he received immediate relief, but the pain never entirely left him, and was much about the same shortly after the operation. About two years afterwards he came up to town and consulted Sir James Clark, who kindly sent him to me. The pain was dull at that time. When the patient walks, even for a

short distance, the pain is much increased, and is also very bad in the first part of the night. Strong pressure has no marked influence upon the pain, but it rather relieves than aggravates it. Besides, the patient states that early in the morning there are usually lively cramps perceptible in the muscles of the leg, which, however, generally subside in the course of the day; as they are not accompanied with any unpleasant sensations, he rather regards them as a curiosity than as an object to be complained of. I first resolved trying Duchenne's proceeding of Faradization of the skin, and made use of a powerful current, which I applied by metallic wires to the painful points. Two such applications, however, produced no effect. In the third séance I therefore sent a very rapidly interrupted induced current of medium intensity through the sciatic nerve, placing the positive electrode near the tuberosity of the ischium, the negative one near the ankle. Moistened conductors were kept in close contact with the skin on the points mentioned, for six minutes; and when I interrupted the application, the pain was quite gone, and the patient left me free from any unpleasant sensation. When he called again on the following day, he told me that the pain had returned about three hours after the séance, but that it was by no means so severe as it had been before, and that he had enjoyed a very quiet sleep that night. I repeated this operation three times again, after which he was obliged to leave town. After the second séance the patient had been free from pain up to the following morning, and after the fourth he only felt

it very trifling when walking, but not while in a quiescent position. Six weeks afterwards I received a note from the patient stating that since this treatment his limb had been a good deal better; he was, however, not totally free from pain when he walked to any distance, yet the pain went off sooner, was less severe, and not so liable to return as formerly. I, therefore, advised him to come up to town once more, to undergo another course of faradic séances. This the patient did some time afterwards. I operated upon him six times more as above, and with such a beneficial effect that the patient was no longer troubled, even when walking the considerable distance of three or four miles. I ought not to forget to mention that the cramps which used to come on early in the morning in the muscles of the leg were not done away with by the electric treatment; but as the patient never found them in any way unpleasant, he did not care for it.

Cases of pain in the back and of infra-mammary pain in hysterical women are generally cured by a short faradic treatment. The infra-mammary pain is generally felt below the left mamma and at the margin of the ribs; I have seen a number of cases of this affection, some associated with amenorrhœa, others not. In those patients who suffered from amenorrhœa, the return of the catamenia and the disappearance of the pain were simultaneous. For infra-mammary pain a stronger current is generally required than for other neuralgic affections, and the action of the current should be kept up for ten minutes. Clavus hystericus is also amenable to electricity.

As to the value of the continuous current in the treatment of neuralgia, some electricians have affirmed that it is just as useful as the induced current. This latter, however, has this preference over the former, that it is more manageable, and can in tic douloureux be applied to the face without danger; while the application of the continuous current to the face is dangerous to the vision. If the continuous current is to be applied, the direction should be inverse.

V. Treatment of rheumatic callosities by electricity.

Dr. Froriep* has strongly recommended the use of electricity in rheumatic effusions which take place in the cutis, the subcutaneous cellular tissue, and the cellular tissue of the muscles. These effusions, according to him, soon become hard and callous, and are to be found in small circumscribed spots or spreading over a large extent; the skin over the callosity cannot be pinched up in a fold. These indurations are accompanied by paralysis and chronic rheumatic pains, which continue for years; if the absorption of the callosities is induced, the pain and the paralytic symptoms which are the consequence will also disappear. As I have already stated, the magneto-electric current possesses a greater curative power against this affection than the volta-electric current, and should therefore be administered with preference in such cases.

* Die Rheumatische Schwiele. Weimar, 1843.

VI. *Introduction of medicinal substances into the human body by the aid of electricity.*

Fabré-Palaprat* conceived that it might be possible to introduce medicinal substances into the human body by the aid of electricity. Thus he relates that he bound on one of his arms a compress, moistened with a solution of iodide of potassium and covered by a platinum disc connected with the negative pole of a voltaic pile of thirty pairs of plates. On the other arm was placed a compress, moistened with a solution of starch, and covered by a platinum disc connected with the positive pole of the battery. He asserts that then in a few minutes the starch acquired a blue tinge, showing that the iodine had been transported from one arm to the other. From these and other experiments he concluded that we may ad libitum cause to remain in the body substances which have been transported by the galvanic current, or cause them to go out of the body after having traversed it (?). To fulfil the first indication, Galvanization should be combined with acupuncture.

These results would certainly be very important if they were correct. But nobody after Fabré-Palaprat has succeeded in showing the transport of iodine from the negative pole of a voltaic pile through the human body to the positive pole. It is therefore almost certain that Fabré-Palaprat has been subjected to an illusion in his experiments. This is also evidenced by his report on the therapeutical value of electricity; as he affirms that he

* Archives générales de mèdecine, vol. ii. p. 432. Paris, 1833.

cured a case of sarcocele of seven years' standing by causing iodine to penetrate into the tumour by the aid of Galvanism; that he cured a case of ague by quinine introduced by the same means into the body; that he cured himself of "ecstatic spasms" by Galvanism, and cured other patients, suffering from blindness, apoplexy, inflammation of the bowels, epilepsy, tænia, monomania, &c.

In 1846, Dr. Klenke* related a great number of more or less intractable diseases cured by the galvanic application of medicinal substances; thus cases of struma were cured by the galvanic introduction of iodide of potassium, cases of syphilis by the galvanic application of sublimate, &c. Dr. Hassenstein† has also published an abstruse account on this subject; but neither Klenke nor Hassenstein have been able to satisfy the Profession as to the accuracy of their results.

In the Medical Times and Gazette for February 12th, 1859, Dr. Richardson published a paper "on voltaic narcotism for the production of local anæsthesia for surgical operations," in which he proposed to produce anæsthesia by a combination of electricity with narcotics. For this he used Pulvermacher's chains and a solution of equal parts of tincture of aconite and chloroform. With this he made some experiments on dogs and rabbits, and afterwards on men; and produced anæsthesia to such an extent, that severe operations which were performed excited no

* Zeitschrift Wiener Aerzte, Mai, 1846.

† Chemisch-electrische Heilmethode. Leipzig, 1853.

or only little pain. The expectations which were at first entertained of this new mode of producing anæsthesia have been somewhat diminished by the results of Dr. Waller's* experiments on the same subject. Dr. Waller found, that the application of a mixture of equal parts of tincture of aconite and chloroform produces loss of vascularity and nearly complete anæsthesia after the lapse of ten to fifteen minutes on the human skin; and that electricity neither retards nor accelerates the production of anæsthesia; that the anæsthesia produced is circumscribed to the spot on which the narcotising mixture is applied, and that it is caused by the local absorption of the mixture; that the absorption of the mixture may produce death in animals, and might perhaps do so in infants and children; and the action of the narcotic mixture, with or without electricity, when applied to the healthy skin, is attended by a severe local inflammation of the most obstinate character, which would be liable to introduce dangerous complications into surgical operations.

In an experiment which I have performed upon myself with chloroform and galvanism, I found that anæsthesia was produced, if a sponge saturated with chloroform was held to the skin for ten minutes, and that the connexion of sponges with the poles of a battery did not sensibly accelerate the action. The pain felt about an hour after the experiment was very severe, and the following day an inflammation ensued which passed into suppuration, which continued for nine days. The pain continued very severe,

* Medical Times and Gazette, March 19th, 1859.

and occasionally prevented sleep; the cicatrices were formed slowly, and earlier on those spots where only the chloroform had been applied; while cicatrization was very tardy on the spots where chloroform and electricity had been directed. This observation is also not favourable to Dr. Richardson's idea of voltaic narcotism.

VII. *Extraction of metallic substances out of the human body: the electro-chemical bath.*

In 1855 M. Poey presented a paper to the French Academy, in which he asserted that it is possible to extract various metallic substances out of the human body by the aid of electricity; whether such substances have been taken as remedies, or whether they have been lodged in the body by absorption in the different arts and trades in which their employment is required. He relates that the first therapeutical essay of this kind was made in 1852, at New York; a man, occupied with electro-plating, had immersed his hands into solutions of nitrate and cyanure of gold and silver, whereby a dangerous ulcer was caused, which resisted the most energetical remedies; at last the patient plunged his hand into the electro-chemical bath at the positive pole, and after a quarter of an hour the metal plate connected with the negative pole was covered by a thin layer of gold and silver. A few more applications of the electro-chemical bath proved sufficient for the cure of the ulcer.

The electro-chemical bath is administered in the following way: the patient is placed up to his neck in a large

metallic tub, which is filled with water and insulated from the ground; he sits in the tub upon a bench of wood, insulated from the tub, and having the length of the body. If mercury, silver, or gold is to be extracted, the water with which the tub is filled is acidulated with nitric or hydrochloric acid; if lead is to be extracted, sulphuric acid is added to the water. One extremity of the tub is connected with the negative pole of a pile of 30 pairs of plates, by means of a screw; and the positive pole is held by the patient alternately in the right and the left hand. The positive electrode is made of iron, and covered with linen, in order to diminish the calorific action of the pile, which is very energetic, and by which the hand might be cauterized. The galvanic current now enters into the body by the right or left arm; it circulates, according to M. Poey's graphic description, from the head to the feet, traverses all the internal organs (sic,) and even the bones, seizes every particle of metal which may exist anywhere, restores it to its primitive form, and deposes it on the whole surface of the sides of the tub from the neck to the feet, and always more abundantly over against that part of the body where the metal is supposed to exist. Thus M. Poey affirms that he once saw in a patient, who complained of pain in the arm in consequence of having taken mercury, the size of the arm delineated upon the negative plate, by the deposit of the metallic molecules which came from this spot. He affirms that he has drawn from the femur and the tibia of a patient a large quantity of mercury which, according to some physicians, had existed in these bones for fifteen years.

Besides the report of M. Poey, only pamphlets have appeared on this subject, written in a low and unscientific tone, and announcing that the electro-chemical bath will prove in course of time something like a universal panacea, not only for paralysis and neuralgia, but also for diseases of the heart and the liver, &c.

Sir Humphrey Davy* has observed that if he immersed his fingers in a vessel filled with distilled water and connected with the negative pole of a voltaic pile, alkalies were excreted from his body and deposited in the water; but if the vessel was connected with the positive pole of the pile, phosphoric, sulphuric, and hydrochloric acid were deposited.

It is true, therefore, that we cannot affirm, a priori, that the electro-chemical bath is devoid of all effect, but there are very strong reasons for doubting its efficacy. In the first place, it is impossible to understand how the galvanic current can convey into the liquid of the bath, and diffuse on the whole surface of the sides of the tub, metallic atoms, which, according to the established laws of electro-chemistry, ought to be deposed only upon the surface of the electrodes. In the second place, it is quite evident that M. Poey has been subjected to a strange illusion in thinking that the galvanic current traverses the *bones* of the patient sitting in the electro-chemical bath. For supporting this view, he quotes Duchenne, who says that if moistened conductors connected with the poles of an electrical apparatus are placed upon the surface of a bone,

* Philosophical Transactions, 1807.

a strong pain of a peculiar character is produced; hence he concludes that if the skin merely be sufficiently moistened, the electric current will traverse the bones! It is scarcely necessary to point out that the pain produced by placing moistened electrodes upon the surface of a bone is caused by the electric excitation of the nerves of the periosteum, and that as the bones conduct sixteen to twenty-two times worse than the muscles and other humid substances of the human body, the electric current will never traverse the bones of a patient sitting in an electro-chemical bath, but will follow the best conducting tissues of the body, viz. muscular and cellular tissue.

It is very probable that the metallic deposits, which have been observed on the sides of the tub, have come either from the skin of the patient or from the electro-chemical bath itself. It is worth mentioning, that a patient who has lately attracted so much notice, and whose case I have been the first to describe in the Deutsche Klinik for December 26, 1857,—viz. Eli B., affected with epilepsy, blackened with nitrate of silver, and recently castrated by Mr. Holthouse,—told me in 1857, when I saw him in Nélaton's Clinique de la Faculté, in Paris, that he had tried the electro-chemical bath at New York, for a long time, to get rid of the black colour, but without the slightest effect. In my opinion, this is a strong case against the electro-chemical bath.

Therapeutical use of electricity in surgery.

The therapeutical application of galvanism in surgery is of more recent date than the use of electricity in medicine;

and while galvanism is indispensable to the physician for the cure of certain diseases, the surgeon may use, in its stead, remedial agents, over which, however, in certain instances, it possesses indisputable advantages. In surgery galvanism may be of use—

1. *As an actual cautery.*

2. *In causing the coagulation of the blood in aneurisms and varices.*

3. *In dissolving urinary calculi.*

4. *In curing ulcers.*

5. *In promoting the absorption of exudates.*

Galvanism has also been applied for—

6. *The dissolution of cataract;* but this does not appear justifiable.

1. *The galvanic cautery.*

Wires, rendered incandescent by the continuous current of galvanic electricity, can be employed for producing the effects of an actual cautery, whether we intend destroying the tissues, or merely modifying their vitality. The first who used a platinum wire heated by voltaic electricity for the production of moxas, was M. Fabré-Palaprat. Professor Steinheil, of Munich, recommended the application of the galvanic cautery for the destruction of the dental nerves in tooth-ache; this operation was first performed by M. Heider. Dr. Crusell, of Petersburgh, recommended cutting and cauterizing the tissues by impressing a backward and forward movement upon the heated wires. Sédillot, of Strasburg, Nélaton, of Paris, and Messrs. Marshall and Hilton, in this country, afterwards used the galvanic cautery for the cure of fistulæ

and erectile tumours. More recently Messrs. Amussat and Jules Regnauld, of Paris, and especially Professor Middeldorpff, of Breslau, have strenuously endeavoured to find out the best way of applying the galvanic cautery. As I have already stated, Professor Middeldorpff's instruments are the best for readily and efficaciously executing the cauterization.

According to Professor Middeldorpff, the galvanic cautery presents the following advantages over other cauteries: it acts rapidly and energetically, and causes little or no hemorrhage; its action may be exactly limited to those parts which we intend to cauterize; deeply-seated structures, which are inaccessible to the knife, may be burnt or cut without danger by the galvanic cautery; which also favours the growth of healthy granulations, and is not so terrible to the patient as red-hot iron.

The use of the galvanic cautery has been recommended for stopping hemorrhage, especially from parts inaccessible to the red-hot iron; as the alveoli, tonsils, throat, orbita, and the frontal sinuses. Besides, it has been recommended for neuralgia of the dental nerves; sciatica; paralysis of the levator palpebræ superioris, and of the facial nerve; in gangrene, for producing a line of demarkation; in ulcers of the cervix uteri; cancer of the tongue, and of other vascular structures; fistula; ectropion, trichiasis, and distichiasis; stricture of the urethra; epulis, etc. I need scarcely mention that for most of these diseases there are other and more efficacious remedies than the galvanic cautery; but there can be no doubt that in some instances it will be invaluable to the surgeon.

2. *Treatment of aneurisms by electricity.*

We have seen in the second chapter that if a continuous current of galvanic electricity is caused to act upon blood, the salts of the blood are decomposed and acids liberated at the positive pole; hence the formation of a clot in the neighbourhood of the positive pole; while at the negative pole alkalies are liberated, and the blood is thereby rendered more fluid. Therefore if we intend to coagulate the blood in an aneurismal sac, a platinum needle connected with the positive pole should be thrust into the centre of the sac, and the circuit closed by placing a metallic plate connected with the negative pole to the surface of the tumour. A trough battery of twenty pairs of Bunsen's, Grove's, or Daniell's battery, feebly charged, will be sufficient for producing the coagulation of the blood, and the current should be kept up for not less than twenty minutes. The drawback to this operation is, that it causes a great deal of pain, and that inflammation of the edges of the puncture, and of the skin covering the aneurism, may follow, and even gangrene may be the result. Besides, M. Broca has drawn attention to the fact that the clot formed by galvanism is rather soft, and liable to be dissolved, as it consists of fibrine and globules, while other clots are exclusively formed of fibrine, and are therefore very hard, and tend to rapid organization.

M. Pétrequin, of Lyons, has cured a traumatic aneurism of the temporal artery, and an aneurism which had been produced by bleeding on the arm (1845.) Since

that time other successful cases have been published; but it is true that such aneurisms easily cede to pressure or ligatures. The galvano-puncture of aneurisms is especially to be recommended in such cases, where the other methods cannot be conveniently applied, on account of the seat of the tumour.

A very remarkable case of aneurism has been published by Mr. Eyre, in the Lancet for July, 1853; in this case not the continuous, but the interrupted (induced) current was beneficially applied. It was an aneurism of the external iliac artery; a pulsating tumour in the left groin, of the size of a fowl's egg; the pulsation was very strong, and accompanied with a bruit which could be traced two inches above the tumour; the limb was swollen and painful. Needles connected with the poles of an induction apparatus were thrust into the sac, and a current sent through it for a certain time. Alarming signs of inflammation supervened some time afterwards, and it was not until seventeen days after the operation had been made, that the tumour felt harder, and the pulsation became fainter; while if the continuous current had been used in the manner described above, the tumour would have become solidified before the withdrawal of the needles. In the case described by Mr. Eyre electricity acted merely as an excitant, and the sac was closed in consequence of irritation and adhesive inflammation, but not by chemical action. As suppuration may easily supervene in such cases, the employment of induction currents for the cure of aneurisms is, generally speaking, not justifiable.

3. *Dissolution of urinary calculi by electricity.*

As far back as 1801, M. Bouvier de Mortier proposed using galvanism for the dissolution of calculi. In 1803, Mongiardini and Lando, tried to dissolve a renal calculus by galvanism, but without success. In 1813, Gruithuisen again recommended galvanism for such purposes, but it was only in 1823 that the first successful experiments on the dissolution of calculi by the aid of electricity were made, by Messrs. Prévost and Dumas.* They at first thought it might be possible to extract the calculus by means of a double sound communicating at one extremity with the bladder, and at the other with two vessels filled with water, and connected separately with the poles of a voltaic pile. They thought that such a proceeding would tend to conduct the bases and acids which enter into the composition of the calculi into the two vessels; but they soon abandoned this idea, because to effect this a current of such intensity would be required as would prove dangerous to the bladder. They therefore determined to try destroying the state of aggregation by which the molecules of the calculus are bound together; because, if once it became friable it would easily come out. They did not, therefore, subject the calculus to a direct chemical action, but employed the mechanical action of torrents of gases for destroying the texture of the calculus.

The following experiments were instituted in order to accomplish this object: a fusible human calculus was sub-

* Sur l'emploi de la pile dans le traitement des calculs de la vessie. In Annales de Chimie et de Physique. Paris, 1823. Vol. xxiii. p. 202.

mitted to the action of a volatic pile of 120 pairs, during twelve hours consecutively. The pile was recharged every hour. Platinum wires serving as electrodes were placed at two different points of the calculus, which was immersed in a vessel filled with pure water. The state of aggregation by which the molecules of the calculus were bound together was therefore destroyed in part, and a fine powder precipitated. At the commencement of the experiment the weight of the calculus was 92 grains; at the end of it, it was reduced to 80 grains. After having been subjected another time to the action of the pile, for 16 hours, the calculus became so friable that the slightest pressure reduced it to little crystalline grains; the largest fragments were scarcely the size of a lentil, and the canal of the urethra would not therefore have opposed their exit. Prévost and Dumas made a similar experiment on a living bitch. A fusible calculus fixed upon a sound was introduced into the bladder of the animal, and the electrodes so arranged that they touched the calculus on separate points. Warm water having been injected into the bladder, the electrodes were connected with the poles of the pile. The calculus was left for an hour in the bladder of the bitch, and when taken out showed unequivocal signs of decomposition. The same process was repeated every morning and evening for an hour each time, on six days successively; after which the calculus had become so friable that the experiment could not be continued. A few days afterwards the bitch was killed and the bladder examined; it was then

observed that the tissue of the bladder did not present any abnormal changes, and that its muscular fibres contracted just as usual, when the organ was opened for evacuating the urine contained in it.

It is obvious that the tissue of the bladder cannot possibly be injured by such a proceeding, because the two contrary electricities always take the shortest way to neutralize each other. The bladder, therefore, would only be injured in case the current applied were of such intensity, that rather strong derived currents would be produced by it, which might act on the mucous membrane of the bladder.

We have seen in the first chapter that a very strong principal current gives rise to only very feeble derived currents. Thus if we place the two poles of a voltaic pile, or of a powerful induction apparatus, in a vessel filled with water, and immerse the fingers in the same vessel, we do not feel the slightest shock, while we feel it very strong if the two poles and the two hands are immersed in separate vessels filled with water, since in this case the two contrary electricities must travel through the human body to neutralize each other. If the two electrodes connected with the calculus are placed in a vessel with water, and the tongue be dipped into the water, no, or only a trifling, sensation of pricking will be perceived in the tongue, even if the current of the battery conveyed by the electrodes be of considerable intensity, although the tongue is exceedingly sensitive to electricity.

In 1835 M. Bonnet, of Lyons,* made some very ingenious experiments with the view of dissolving calculi by the chemical action of the continuous current. He placed different calculi between platinum electrodes immersed in a solution of a drachm of nitrate of potash in four ounces of water, and partially succeeded in destroying the stones, by directing a continuous current to their texture. Calculi of oxalate of lime were the only ones which resisted the action of the current, while calculi of every other description were dissolved more or less rapidly. The point established by the researches of M. Bonnet is, that we may convey acids and alkalies, merely by the electro-chemical decomposition of a saline solution, without these powerful substances being diffused in the urine contained in the bladder. We know that most urinary calculi are dissolved either by nitric acid or by potash; but how can these substances be introduced into the bladder without cauterizing its tissue? If a solution of a neutral salt, such as nitre, is injected into the bladder containing the calculus, and the electrodes connected with the poles of the pile are made to touch opposite surfaces of the stone, a decomposition of the solution of nitre will be brought about, and the nitric acid will be attracted to the positive pole, the potash to the negative pole; and one of the sides of the calculus will be subjected to the action of the nitric acid, the other to that of caustic po-

* Exposé sommaire de quelques expériences sur la dissolution des calculs vésicaux; in Bibliothèque universelle de Génève, 1835. Vol. lviii. p. 391.

tash. Now, if the stone be composed of phosphates, it will be dissolved on the acid side; if it be composed of uric acid, or urate of ammonia, it will be decomposed on the alkaline side. But while this process of dissolution is going on, the calculus and the mucous membrane of the bladder are always immersed in a neutral solution. When the action of the current is kept up, the electrode will gradually penetrate to the interior of the stone, but always on one side only, according to the chemical composition of the stone. In this way stones of phosphate of ammonia and magnesia; phosphate of lime, ammonia, and magnesia; urate of ammonia and uric acid are capable of being decomposed. If the texture of the stone be very dense, the dissolution will be confined to the point touched by the electrode, but if the stone be formed of layers which are only feebly connected with each other (as are stones of urate of ammonia and treble phosphates,) or if it be porous (as are stones of phosphate of ammonia and magnesia,) the calculus soon becomes friable, and the layers are separated from each other. The dissolved part does not remain in solution in the liquid, but is precipitated as a fine powder of subphosphate, or of uric acid.

In the course of his experiments, M. Bonnet changed the salt solution in which the calculi were immersed; he tried the phosphate, the muriate, and the borate of soda, and the fluate of potash; but he found none of these salts exercised such a general and powerful action as nitre. If nitre is dissolved in the urine of a healthy man, in-

stead of in water, phosphatic calculi are more powerfully, and uric acid calculi more slowly, acted upon. By the action of the continuous galvanic current, the salts of the urine are decomposed, acids being attracted to the positive, and alkalies to the negative, electrode.

Similar experiments were undertaken by Dr. Bence Jones, in 1853,* who confirmed nearly all the results previously obtained by M. Bonnet, but found that calculi of oxalate of lime, which had been pronounced indissoluble by M. Bonnet, could be dissolved, although only slowly.

The only author who affirms having operated in this way upon living men, is Dr. Melicher, of Vienna.† He used a voltaic pile of 100 plates, and Bunsen's pile of 30 pairs, and by the aid of these batteries dissolved calculi, at first in a vessel filled with water, afterwards in an animal bladder, and at last in the bladder of patients suffering from calculous disease; he states that he has invented an instrument by which it is easy to take hold of the stone in the bladder, so as to expose it to the action of the current; and that he has operated successfully in two cases, in which the dissolved parts of the stone were discharged with the urine.

The mechanical action of an electric discharge has also been recommended for disintegrating calculi. Elec-

* On the dissolution of urinary calculi in dilute saline fluids at the temperature of the body by the aid of electricity. Philosoph. Transactions, 1853, p. 201.

† Die Effecte des Galvanismus auf Harnsteine, in Oesterreichische Medicinische Jahrbücher, 1848, p. 153.

tricity of high tension produces very remarkable effects in destroying the molecular structure of imperfect conductors; thus it is well known that lightning causes breaking and pulverization of stones, panes of glass, and other similar bodies which it cannot traverse without destroying them. Proceeding from these facts Mr. Robinson has tried to break calculi by discharging through them a Leyden jar, and he has succeeded in pulverizing phosphatic, mulberry, and lithic acid calculi, which were previously placed in a bladder or in vessels of glass or earthenware filled with water; while no effect was produced if the surrounding medium was air. He has recommended to introduce two conducting wires through an elastic catheter into the bladder; the wires being connected separately with the inner and the outer coating of the jar, and their free extremities being separated in order to grasp the stone. However ingenious Mr. Robinson's idea, it is more likely that the chemical action of the continuous current will eventually prove more manageable in the hands of the Surgeon than the mechanical action of static electricity.

4. *Treatment of ulcers by galvanism.*

Dr. Crussel, of St. Petersburgh, has first used the chemical action of the continuous current for the treatment of certain ulcers. This method is called by him the electro-lytic treatment, and has afforded in many patients in the naval hospital of Cronstadt very striking results, in favouring the growth of granulations and the cicatri-

zation of ulcers. In the opinion of Mr. Spencer Wells, who has also made many trials with galvanism in the treatment of ulcers, there is no means so capable of producing a rapid growth of healthy granulations as the continuous current, and often a very beneficial change is effected in the condition of ulcers within 24 hours. Mr. Wells found that if two slight excoriations, two ulcers or suppurating surfaces upon a limb or any part of the body were subjected to the action of a single galvanic pair, the zinc being applied upon one and the silver upon the other, the surface beneath the silver rapidly cicatrized, while that beneath the zinc was in two days converted into a superficial eschar. To insure the passage of the current it is not necessary to denude but only to moisten the cuticle. If the plates be still kept applied, the eschar extends to the subcutaneous cellular tissue, and presents all the characters of a slough produced by caustic potash, except that the dead tissues are a little less compact. After the separation of these sloughs cicatrization under ordinary applications is very tardy, but it sets in at once if the silver plate be applied, the zinc being fixed on some neighbouring part.*

5. *Absorption of exudates by the aid of electricity.*

Willebrand, Dr. A. von Graefe, and Dr. Meyer have obtained very good results of the application of electricity to opacities of the cornea. Dr. Meyer recommends to place a moistened sponge connected with the negative

* Appendix to Dr. Golding Bird's Lectures on Electricity and Galvanism; and various papers in the Medical Times and Gazette.

pole of an induction apparatus upon the closed eye, and another electrode in the hand of the patient. Dr. A. von Graefe states that in opacities of both corneæ he employed on one eye electricity, and nitrate of silver or laudanum on the other eye; and that the cure was sooner effected in that eye which had been acted upon by electricity.

Professor Pétrequin has published a case of hydrocele cured by the application of the continuous current, and it is probable that serous exudations will generally yield readily to the application of electricity.

6. *Dissolution of cataract by electricity.*

Crussel and Lerche* have made experiments on the dissolution of cataract by the aid of electricity. They found that if the zinc pole of the voltaic pile is applied to a lens, this is rendered opaque; and that the opacity disappears if the copper pole is afterwards directed to the lens. Hence they concluded that it might be possible to dissolve cataract by the application of the negative pole of the pile to the eye. Matteucci† asserts that cataract cannot be dissolved by electricity; but we have the authority of Dr. A. von Graefe‡ for the contrary. It is, however, not allowable to employ galvanism for the dissolution of cataract, as in the few cases which have thus been treated by Crussel, inflammation of the choroidea, iris, and retina, and destruction of the eyeball followed the operation.

* Medizinishe Zeitung des Vereins, etc. 1841.

† Cours d'Electrophysiologie. Paris, 1858.

‡ Deutsche Klinik, 1852, p. 415.

Therapeutical use of electricity in midwifery.

Bertholon in France, Herder, Stein, and Kilian in Germany, and Drs. Radford and Barnes in this country, have recommended and used electricity in cases of tedious labour and hemorrhage from the uterus, especially in some forms of placenta prævia; and for originating uterine contractions in cases where it is necessary to induce premature labour. As to the mode of application, Kilian has recommended applying a galvanic forceps, the blades of which consist of two different metals. Dr. Radford proposed the application of one pole to the abdominal parietes over the fundus uteri, the other to the os uteri by means of a vaginal conductor. Mr. Cleveland, on the contrary, has directed the two poles to the abdomen externally, and the same proceeding has been adopted by Dr. Barnes, while Dr. Mackenzie has insisted that it is necessary to apply the positive pole to the nape of the neck and the negative to the cervix uteri, if we wish to act energetically upon the contractile fibre-cells of the uterus.

Professors Simpson and Scanzoni consider electricity in midwifery all but useless, and suppose that when uterine action has apparently been excited by galvanism, this has been either a mere coincidence, or it has resulted from the impression made on the mind of the patients, or been produced by mechanical irritation of the uterus or the abdominal parietes by the electrodes. Recent experiments, however, which have been undertaken by Dr. Mackenzie seem to confirm that in cases of placenteal

presentation, in which profuse hemorrhages continue to recur, notwithstanding the employment of the plug and other means, before the os is sufficiently dilated to admit of manual assistance; and in cases of hemorrhage in the early months of pregnancy, which resist other treatment, and which from the constricted state of the os and cervix uteri do not admit either of mechanical or manual interference, induction currents are invaluable.

In conclusion, a few words may be said on the accidents which may be caused by an injudicious application of electricity. This powerful agent is not one of those remedies which, if they do no good, can do no harm; but on the contrary, it may, in the hands of an inexperienced operator, do a great deal of mischief. Thus blindness has been caused by the application of the continuous current to the face in paralysis of the portio dura; fainting, cramps, hysterical fits, and palsies have been produced by administering too powerful currents; and fresh apoplectic attacks have been induced in patients who had suffered before from hemorrhage into the brain. Accidents of this kind can only be avoided if the operator is guided by physiological knowledge and sufficient therapeutical experience. In this remedy more than in any other the mode of application has an all-important bearing upon the results; for it is not electricity that cures diseases, but the Physician, who may cure diseases by means of electricity.

APPENDIX.

ATMOSPHERIC ELECTRICITY AND LIGHTNING.

When the sky is serene, the air is charged with positive electricity, which, however, cannot be collected immediately above the ground, since the earth is charged with negative electricity, and the two contrary fluids continually re-unite to zero in the lower layers of the atmosphere. It is only at about three feet above the ground that the action of positive electricity becomes sensible; its quantity increases in proportion as we rise, so that it may be easily collected from the air by means of elevated and insulated metal rods, through which it may be drawn down to the wires of a galvanometer; if this be done, the magnetized needle is deflected more or less strongly in proportion to the quantity of electricity obtained. The quantity of amospheric electricity is largest on the summits of mountains, and it is probable that at least some of the curious physiological phenomena observed by travellers in considerable heights, such as the tearing of delicate blood-vessels, etc., may be due to the powerful action of positive electricity upon the body, since the chemical composition of the air remains unchanged on the summits of mountains.

The quantity and tension of atmospheric electricity differ according to the time of year and hour of the day. They are

considerable when the days are short, and trifling when they are long; the maximum is attained in February; it then rapidly diminishes during the following three months, and reaches its minimum in June. It then rises slightly in July, but is again diminished in August; from that time it steadily increases until it reaches its maximum in February. There are likewise somewhat constant variations in the intensity of atmospheric electricity in the different hours of the day. The first or night minimum is at 2 A. M.; from that hour an increase is observed until 10 A. M., when the first or morning maximum is reached. Thence it is diminished until 4 P. M., when we observe the second or day minimum; after that the tension again increases up to 10 P. M., when the second or evening maximum takes place, the latter being far greater than the first or morning maximum.

The electric state of the atmosphere just described undergoes considerable alterations when the sky is not serene. During fogs the quantity of atmospheric electricity is very much increased. The same has been observed at the approach of, and after, rain and storms. When rain is very distant from the place of observation, the magnetized needle indicates positive electricity as usual; but when it approaches within a certain distance, a powerful negative electricity is observed, and immense electric sparks are produced, viz., *lightning*, the discharge of which is usually accompanied with a tremendous noise, viz., *thunder*. When the rain falls vertically, the needle indicates positive electricity, but is again deflected in the contrary direction, when the rain withdraws from the place of observation.

We have reason to believe that the principal source of atmospheric electricity is the evaporation of salt water from the immense surface of the ocean, which is continually going on,

especially in the tropical regions, where evaporation is very much favoured by the intense heat. The vapours emanating from the surface of the ocean rise at first more or less vertically, but are soon afterwards horizontally dispersed over the two hemispheres by the current existing in the higher regions of the atmosphere. These vapours are the vehicles by which the positive electricity is constantly carried into the air, whilst vapours negatively charged proceed from the moisture contained in the earth. As this evaporation is trifling in cold weather, we rarely find much negative electricity in the air during winter, which therefore is not the season of storms. In summer evaporation from the moisture contained in the earth is very abundant, and a few degrees of cooling will then cause a considerable condensation of vapours, viz., storm-clouds carrying a large quantity of electricity. Each cloud consists of an innumerable multitude of small globules charged with electricity, and when a very large quantity of such globules are collected in a small space, storms are produced, the extreme violence of which, especially in tropical regions, is well known.

When the air is strongly charged with electricity, as is the case before and during storms, various disturbances of the nervous system are observable in many persons, especially women—which may be partly due to mental anxiety and fear of danger, but in numerous instances are undoubtedly primitive effects of electricity upon the body. I knew a person who always fell asleep on the first signs of an approaching storm. Others are subjected to nervous excitement or oppression, or a feeling of weariness and disinclination to work is produced. Not unfrequently dyspnœa due to emphysema and heart disease gets worse; patients suffering from chronic rheumatism and neuralgia mention an increase of pain; paroxysms of intermittent fever pre-

cede the time at which they had been expected to commence; in acute diseases, especially in pneumonia, the symptoms grow more alarming, and in fatal cases death will arrive earlier in stormy weather than might else have been anticipated.

The effects of lightning on the human body are extremely various. M. Boudin, a French philosopher, who has devoted much study to these phenomena, describes them as "unforeseen, proteiform, involved in contrasts, opposition, and mystery." Thus lightning may kill by a single stroke, or only produce muscular paralysis, blindness and deafness; and it may also cure the afore-named diseases. Tulpius relates the case of a young man who had been dumb for three years after the removal of half of his tongue. This man felt a sudden movement in the remaining half, and immediately recovered his speech, in consequence of the shock given him by a vivid flash of lightning followed by a violent clap of thunder. Professor Olmsted has recorded the case of a man, named Samuel Leffers, who, after having been blind for a long time, was restored to sight by a flash of lightning. In persons killed by lightning we may find extreme rigidity of the limbs, while in other instances the muscles are quite flaccid; and putrefaction of the body sometimes commences very soon, and in other cases it is very tardy.

We gather from approximative calculations that in the whole world about 4000 persons per annum are killed by lightning, which gives far more formidable shocks than any we can produce by the most powerful electrical machines. The number of deaths differs in different countries, and generally speaking is proportionate to the frequency and violence of the storms which occur in them. Thus we know that the rate of deaths by lightning is about 140 per annum in France, while in this country only 22 per annum are killed. As most storms occur during

June, July, and August, it is no matter of surprise that in these months the largest number of fatal cases are always recorded.

Some persons are naturally better conductors of electricity than others. This is partly due to the extreme variety which exists in the quantity of perspiration in different individuals. Persons who perspire copiously will be more exposed to danger from lightning than others whose skin is generally dry. Besides, the nature of the dress is very important; ladies dressed in silken robes are seldom in danger of being hurt. Animals seem to be more easily affected by the destructive action of lightning than man; large flocks have been killed by a single flash, while the shepherd was not hurt; dogs and horses have been struck, but the life of the hunter was spared. In a storm which occurred in August, 1846, in the canton of Levroux, a group of labourers was struck by lightning; four were killed and six severely wounded; one of the men had worn a goat-skin, and on his body there were the most severe lacerations, and in three hours after death it became as rigid as a bar of iron.

There was a time when it was generally believed that we might be able to paralyze the effects of lightning by ringing church bells; hence an inscription not unfrequently found on bells: *vivos voco, mortuos plango, fulgura frango.* Such a belief and practice has caused not a few fatal accidents to the ringers: lightning strikes with preference elevated objects, such as towers; it is attracted by the metal of the bells, and conducted through the wet strings, by means of which the bells are pulled, to the hands of those who think themselves entirely out of danger.

It is probable that in many instances death from lightning takes place in consequence of the shock to the centres of the

nervous system, the vitality of which may be destroyed at once. We suppose such to have been the case when we do not observe any structural changes in the bodies of the persons killed. Dr. Brown-Séquard has advanced the opinion that death may also be caused by asphyxia, resulting from a sudden and extremely violent contraction of the respiratory muscles produced by the electric shock; thus respiration becomes suspended, and death is caused by an accumulation of carbonic acid in the blood. According to the same author, the latter is the usual way in which animals are killed by strong electrical discharges. This agrees with the fact that it is far easier to kill animals by a shock directed to the abdomen (diaphragm) than to the head. If severe shocks from electrical machines are given to animals, we generally observe that the respiration ceases with the stroke. After having received the shock, the animal may still open its mouth widely, as if gasping for air; but there being no motion of the thorax, the efforts will prove unsuccessful, and after a short time cease altogether.

Common post-mortem appearances are: congestion of the blood-vessels of the cerebral membranes, especially of the choroid plexuses; of the lungs, the stomach, and the intestines; the liver, spleen, and abdominal muscles, while the cavities of the heart are generally nearly empty. Coagulation of the blood has not been recorded as a consequence of lightning-stroke; on the contrary, in some instances the blood has been found more fluid than is usually the case. This may favour the putrefaction of the bodies, especially when blood-vessels have been torn by the shock, and an effusion has consequently taken place into the tissues; thereby generally more or less extensive swellings are produced.

By the calorific action of lightning the clothes may be set on

fire, and the body may appear much burnt: a partial or total depilation of the body and various eruptions on the skin, as erythema, erysipelas, urticaria, have also been observed. Lightning has produced on the skin exact photographs of surrounding objects, such as trees, ships, or pieces of money, which those struck by lightning happened to have in their pockets. If persons thus injured have not been killed by the stroke, the marks produced on their skin have remained during life.

The mechanical action of lightning, which often causes breaking aud pulverization of stones, has occasioned fractures of bones which offer a great resistance to the passage of electricity. Holes in the head, extensive comminutive fractures of the skull, have been observed. The eyes, the tongue, even whole limbs, have been torn off the body, and hurled to a considerable distance from the spot on which the accident occurred; the bodies are sometimes completely stripped and the clothes scattered far away.

According to Hunter and Himly muscular rigidity is not observable in bodies killed by lightning. But in this they are mistaken, as in a few cases only flaccidity of the muscles has been recorded. On the contrary, we find in most instances an extreme stiffness of the muscles, which may be as rigid as bars of iron. It is a very remarkable circumstance, that persons who have been killed have remained long afterwards in the same position in which they were when struck; either standing erect, sitting or ou horseback; the state of the muscles resembling that observed in catalepsy. In the Philosophical Transactions of the Royal Society, for 1781, a case is related of a man who was struck by lightning while standing near the window in his room; every pane of glass was completely smashed, and he was thrown several yards from the window upon the floor on his back, with

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both his legs upright in the air, in which position he remained for some time. He was quite sensible of his situation, but could not open his eyes nor speak, nor had he the least power of moving any of his limbs for a long time. The inside of the sleeves of his coat, waistcoat, and shirt were torn entirely open, as if by a dog; the brass buttons and the watch-chain melted, and the going of the watch stopped. His right arm, right side, and thigh were scorched and the flesh torn, and one of his toes split almost to the bone. In the same house two servants were struck dead, but their limbs remained flexible up to the time of interment, which took place two days afterwards; besides, two ladies were driven to a distant part of the room and rendered insensible, but were not hurt.

If the shock has not entirely destroyed life, it may still induce serious complaints. M. Boudin quotes the case of a man who, after having been struck by lightning, did not show any signs of life until an hour and a quarter after the accident, notwithstanding every available assistance had been bestowed upon him. At last he recovered his consciousness and intellect; but his sight was gone, sensation was obtuse, and motion difficult; besides he suffered from cramps in the limbs, head-ache, and drowsiness; while the sense of smell, taste, and hearing had acquired greater delicacy. This patient, at the end of four months, entirely recovered under medical treatment.

THE END.